December 1953

NUCLEONICS

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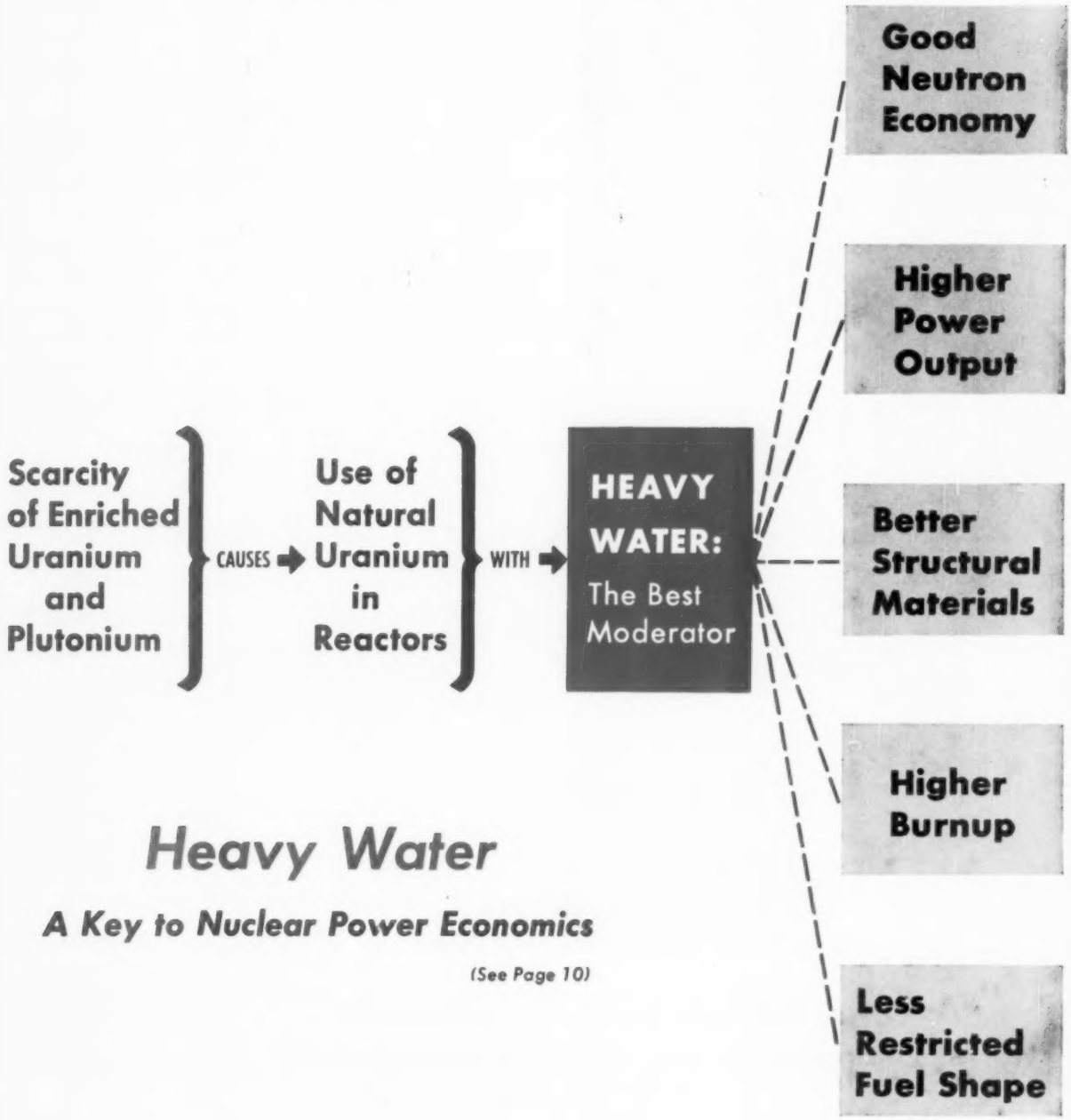

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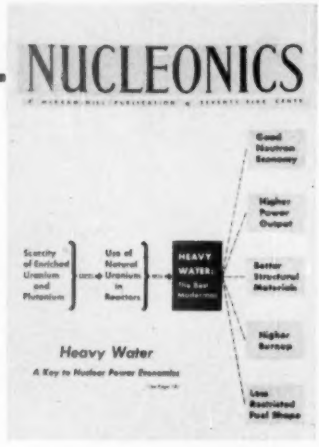

DECEMBER • 1953

Vol. 11, No. 12

"Our New Urgent National Goal—Development of Economic Nuclear Power"... 8
THOMAS E. MURRAY

International Developments in Heavy Water Reactor Technology... 10
J. A. GOEDKOOP

The Future of Heavy Water Reactors... 10
L. KOWARSKI

Ionization-Chamber Device for Clinical Gamma-Ray Use... 15
M. A. BULLEN

Current Research in Radiobiology... 18
ALMA HOWARD and MICHAEL EBERT

Absolute Beta Measurement of Tritium Monolayers... 24
D. E. BEISCHER

Experimental Techniques in Beta-Ray Spectroscopy—I... 28
C. SHARP COOK

Application of Isotopic Sources to Food and Drug Sterilization... 32
L. E. CREAN, P. J. ISAACS, G. J. WEISS, and F. FAHNOE

Fast-Coincidence Circuit for H^3 and C^{14} Measurements... 38
R. D. HIEBERT and R. J. WATTS

Radioisotopic High-Potential, Low-Current Sources... 42
JOHN H. COLEMAN

Properties of Long Columns of Scintillating Liquids... 46
W. A. SCHNEIDER, J. HERSHKOWITZ, and H. KALLMANN

Evaluating Beta Energy Dependence in End-Window G-M Tubes... 49
U. L. UPSON

INDEX to Volume 11, 1953... 81

Cross Sections

Windowless Gas-Flow Counter Operated as a Continuous Flow Counter... 58
A. H. EMMONS and J. A. NORTON

On the Artificial Radioactivity of Rainfall... 59
P. E. DAMON and P. K. KURODA

A Versatile Method for Micro-Autoradiography... 60
FRANK E. HOECKER, PAUL N. WILKINSON, and JACK E. KELLISON

Apparatus for Intracavitary Administration of Colloidal Gold... 65
ROSALYN S. YALOW and BENJAMIN B. COHEN

Departments

EDITORIAL..... 7
BOOKS..... 68
NEWS..... 70
LETTERS..... 69
PRODUCTS AND MATERIALS.... 74

JEROME D. LUNTZ, Editor
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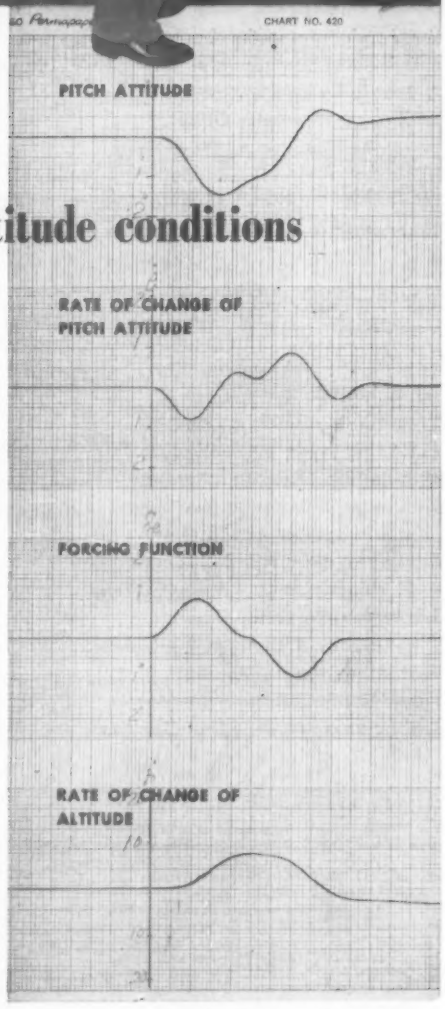

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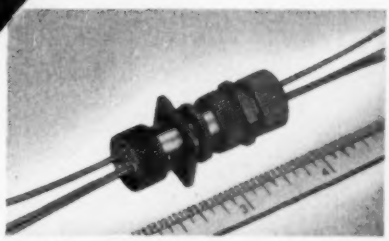

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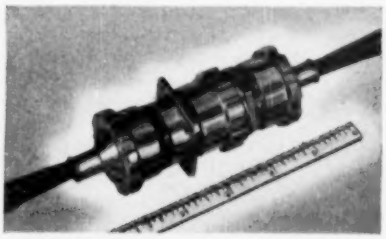

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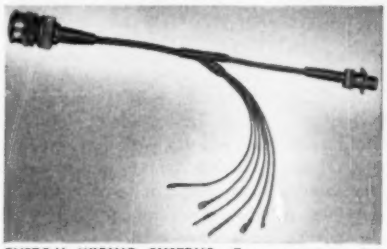

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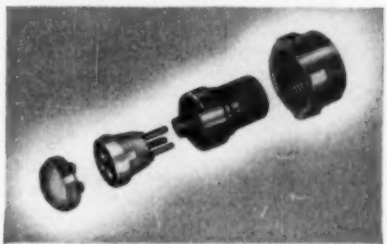

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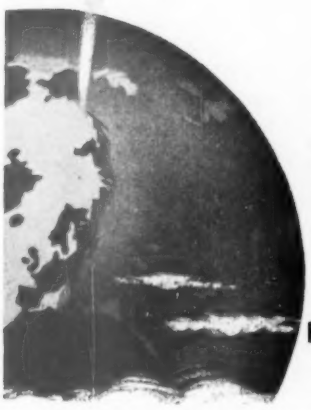

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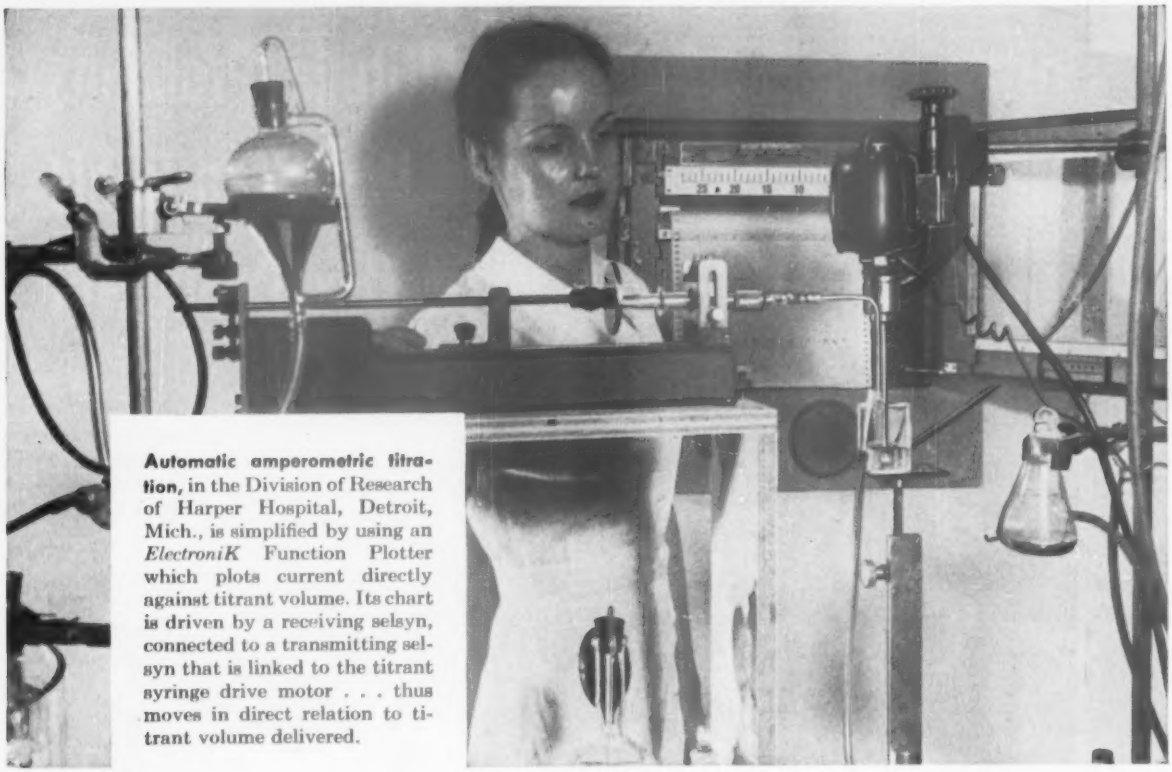

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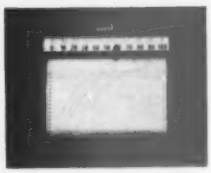

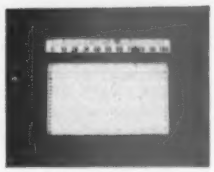

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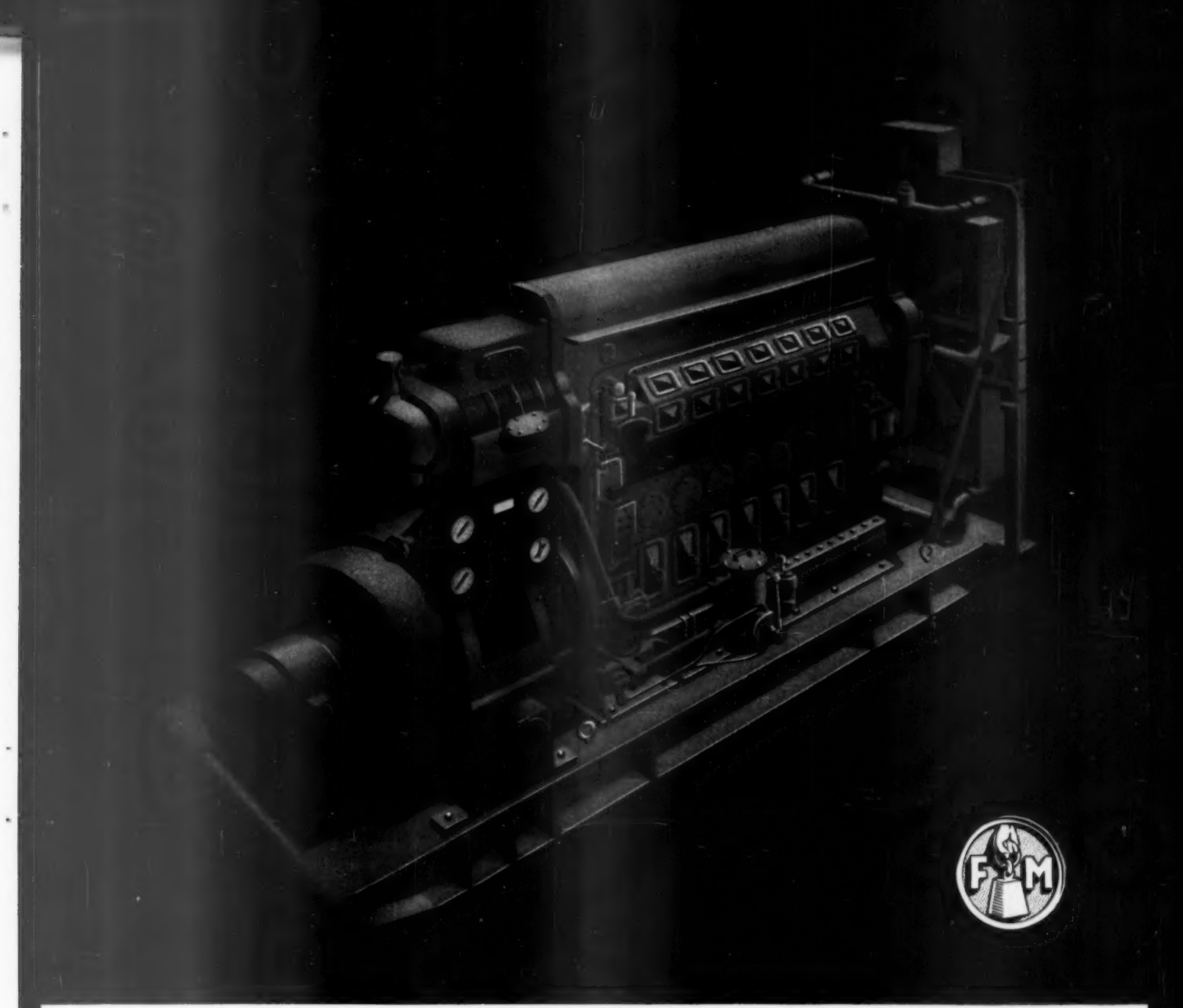

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FAST OPERATING—laboratory technician pictured above is comparing the reading of a Victoreen standard pencil with a previous reading. She can accurately read 100 pencils in less than 15 minutes.

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NUCLEONICS DECEMBER, 1953

Jerome D. Luntz, *Editor*

Pros and Cons of the PWR

AS REPORTED in this issue (p. 70), this country is finally embarked on building a civilian power reactor. The Atomic Energy Commission says that this is to show the world that "America's eyes are still on the peaceful future." At the same time, we have formally entered into a race with Russia to beat her in the achievement of practical industrial nuclear power. Actually this is a mythical race since what is "practical" in one country may not be "practical" in another.

Up until this time AEC's program for civilian power was tied to military propulsion work. Every power reactor being built or planned for building had a military objective as its primary motivation. Civilian activities were byproduct to this work.

The CVR project—aircraft carrier reactor—contracted for in mid-1952 was to be the first relatively large power reactor (about 75,000 electrical kw). It was expected that much engineering data would come out of this that would be useful in a civilian plant. But because of the military goal, economy was no objective, and the results would not clarify the picture much dollars-and-cents-wise.

Then, in May of this year, the Defense Department canceled work on the CVR. But Robert LeBaron, chairman of AEC's military liaison committee and assistant to the Secretary of Defense, says: "We still have military requirements for . . . the CVR. . . We want it promptly." But he says the military has not wanted to freeze a design. "At this stage of the game," states LeBaron, "it is primarily the Commission's responsibility to develop the reactor, and our military judgment on it won't be finalized until progress is further along the road."

After cancellation of the CVR, it was primarily through efforts of the Joint Committee on Atomic Energy that money was obtained for AEC to build a civilian version of the CVR (the PWR). Because of the Navy-Westinghouse experience on pressurized light water systems (STR and CVR), this same team was picked for the PWR.

THE DECISION TO PROCEED with building the full-scale PWR (expected to be about the same size as CVR's anticipated 75,000 kw) was based, according to Commissioner Murray, on our need to get going in this field. "We were persuaded," he says, "that we had much to learn that could only be learned by building and operating. . . We recognize that costs of power, derived from this first reactor, will be higher than costs from modern plants. But we will never really know the answer to costs until we build and operate several large-scale reactors."

Despite Congressman Cole's statement last month that there is no disagreement over plans for the PWR, there is in fact considerable difference of opinion on the project. The most frequent criticism has been that a military group has been put in charge of a civilian project.

In evaluating the PWR, it is helpful to use criteria set up by W. H. Zinn, director of Argonne National Laboratory. He said that there are four basic questions that should be answered in deciding on any power reactor project: (1) How much will it advance the art? In other words, what return will we get from the work? A lot of money shouldn't be spent on a project that brings little knowledge in return. (2) How much closer will it bring us to economic power? (3) Will it help us meet Soviet competition in the power field? (4) If we have in mind as one goal for a project the desire to export technology developed to friendly nations, then can these nations use the technology we develop? For example, if the reactor is to use plutonium or enriched uranium as a fuel, we should consider whether the nations we have in mind have such fuels.

MANY FEEL THAT PWR is one of several worth building on a full scale now. Of those feeling this way, there are some on the AEC staff who say that cost is not an important factor. Even if the reactor were gold-plated, they say, the important aspect is getting engineering data. In this sense, they feel, the reactor can be considered to be a pilot-type plant even though it is full scale.

On the other hand, typical of other comments is that of P. N. Powers of Monsanto: "The [PWR] . . . will undoubtedly provide valuable experience and information, but so far as industrial development is concerned, it tends to confuse the picture. . . The power will be so expensive that it may in itself give little impetus to getting private capital into the field." It has been predicted that capital costs will be about $1,000 per electrical kw.

Another comment, that of George Weil, formerly of AEC's reactor division, is of particular interest in light of the statement by LeBaron (above). Weil says: "It is not difficult for me to imagine that a Government project initiated today with the single objective of producing power for civilian or industrial use would have its objective changed to provide power for an aircraft carrier at some later stage in its development."

But perhaps one of the most pointed remarks is one made by Zinn: "Technically, we are making power right now in perhaps three places. So there isn't any question that, technically, it can be done. What is at issue is: 'Can you make it at a price that anybody wants to pay?'"

On the question of developing exportable technology, it is reported that the PWR will use enriched uranium. Thus, as far as a country like Belgium is concerned, if we want to assist them, we will have to give them enriched fuel since they have no gaseous diffusion plants.

Most answers to Zinn's questions appear to us to be negative. Underlying the prevailing attitudes is despair regarding the economic possibilities of the project. The Navy-Westinghouse team has done very well where it has had a goal of getting a reactor built in short order. If instead of merely trying to get the PWR built for the sake of having an operating civilian power reactor Navy-Westinghouse has the economics of the system uppermost in its planning, this country may approach its goal in the world nuclear power race—practical nuclear power rather than just nuclear power at any cost.

In one of the most forceful talks* made by a commissioner of the AEC, Mr. Murray has translated into action terms the goal of this country to achieve competitive nuclear power

"Our New Urgent National Goal —Development of Economic Nuclear Power"

By THOMAS E. MURRAY
Commissioner
U. S. Atomic Energy Commission
Washington, D. C.

A VIGOROUS AND SUSTAINED atomic weapons program, on our part, is, unfortunately, one necessary cost of proving conclusively that war is rapidly becoming obsolete. But there is another cost, the cost of demonstrating the greater importance of peaceful use of atomic energy—it is the cost in terms of faith, dollars, and effort in proving up the immense utility of industrial atomic power. We are challenged now, today, to step up to this latter cost—to accomplish this technological breakthrough. I would like to consider with you some of the Commission's plans for meeting this challenge. I am convinced that hope for a peaceful future depends in no small measure upon early success by the United States in meeting this challenge—industrial atomic power.

Early this year the Atomic Energy Commission submitted to the National Security Council a statement of policy on the development of nuclear power . . . The goal of achieving nuclear power development, which is a most difficult one, seems to be taken for granted. In my experience, goals or beliefs, that are taken for granted are apt not to generate much drive, enthusiasm, or interest. And, as I firmly believe that the goal called for by our nuclear power policy is essential to the continuation of American leadership in the world, I thought it well to take this occasion today to develop for you some of the background of our power policy and the reasons why I subscribe to it.

Our people badly need direction. We will not win this power race unless, as a nation, we have as great a will to win it as we have to stay ahead in the weapons race. And that will can only be based on a much greater general knowledge and appreciation of the nuclear power situation.

Last month, when news was released of a thermonuclear demonstration in Soviet Russia, a shudder went through the whole world. Yes, through the whole world, for even in the Soviet-dominated world there must now be some sharing of the dread with which this news is being met in the free world. But I would like to propose for your consideration that this recent USSR accomplishment, great as we must admit it to be, is less dangerous today to the free world's hopes for the end of Godless tyranny than would have been the case if the Soviets had announced that day that it had been successfully operating a practical industrial nuclear power plant—and was that day offering foreign nations nuclear power technology in exchange for uranium, coupled with other favorable economic and political agreements.

It is no secret that our atomic weapons program depends upon the receipt of substantial quantities of uranium from foreign nations. These friendly nations, I think, are motivated mainly by two beliefs. They believe in the military protection afforded by our atomic weapon potential. But we sometimes are inclined to forget that they also are betting on our great record of success in solving industrial and technological problems. They are banking on United States know-how and United States good faith to help them build their nuclear power plants of the future.

I believe that unless we embark on an all-out attack on our nuclear power

* Before Electric Companies Public Information Program, Chicago, Ill., Oct. 22, 1953.

TIME FOR ACTION: MURRAY

"U. S. nuclear power policy calls for early development of practical power reactors . . . This means attacking the problem on a broad front, extending from our weapons material producing reactors at one extreme, through military propulsion reactors, through Government-financed full-scale power-producing units, all the way to privately financed research, development and ultimately private construction of full-scale units."

"This recent USSR accomplishment [of a thermonuclear weapon] . . . is less dangerous today to the free world's hopes . . . than would have been the case if the Soviets had announced that it had been successfully operating a practical industrial nuclear power plant."

"Unless we embark on an all-out attack on our nuclear power program immediately, we may be deprived of foreign uranium ores."

"The time has come to end the monopoly of power reactor information now shared between the Government and a few industrial concerns in order to permit much wider participation under appropriate security controls."

"We must . . . avoid . . . power myopia . . . We may be looking right at some [other] uses for atomic energy of tremendous significance and not seeing them"

program immediately, we may be deprived of foreign uranium ores with the result that our weapons potential will be smaller than need be the case.

Once it is accepted that our uranium supply may be, to some extent, dependent on early success in the power race, it should be quite clear that the stakes are high. Once we become fully conscious of the possibility that power hungry countries will gravitate toward the USSR if it wins the nuclear power race, regardless of the aversion they have for tyranny, it will be quite clear that this power race is no Everest-climbing, kudos-providing contest.

As Chairman Sterling Cole of the Joint Congressional Committee on Atomic Energy said publicly last June: "The possibility that Russia might actually demonstrate her allegedly peaceful intentions in the field of atomic energy, while we are still concentrating on atomic weapons, would be a major blow to our position in the world."

This then is the background, as I see it, of your Atomic Energy Commission's nuclear power policy of 1953. Viewed in such light, the policy statement becomes much more than just a framework for liberalizing amendments to the Atomic Energy Act. This fundamental purpose stands out clearly in the initial paragraph of the Commission's power policy statement which reads in part:

"We believe the attainment of economically competitive nuclear power to be a goal of national importance.* * * It would be a major setback to the position of this country in the world, to allow its present leadership in nuclear power development to pass out of its hands."

Until recently defense demands have limited large scale nuclear power efforts primarily to military propulsion projects, such as submarine reactors. But the world situation, as well as the evolving progress of reactor technology, now call for a great change of pace. With this in mind the Commission has decided that it is time for full-scale construction. [See p. 70].

But before making this decision we had to answer a fundamental question —would private industry, if permitted to do so by law, enter aggressively into the full-scale power reactor construction and testing stage. The answer that we derived after several years of probing this problem, with the help of competent interested industrialists, was negative.

In the immediate future we expect to propose the construction of different types of reactors that will explore promising avenues of approach to practical nuclear power. In addition, we will continue our general programs of research and development in line with the Administration's decision to get on and get ahead in the power reactor field. This then is a brief description of our proposed implementation of another point in the Commission's power policy which reads:

"Accordingly, we recognize it as a responsibility of the Commission to continue research and development in this field and to promote the construction of experimental reactors which appear to contribute substantially to the power reactor art and constitute useful contributions to the design of economic units."

And now let us consider the political and controversial subject of industrial participation—the only phase of the Atomic Energy Commission's civilian power program which has generated any heat so far! My career "in real life" was in business. A fundamental principle of my economic thinking is that the government should not undertake industrial jobs which can be done well by private enterprise. I have tried, for more than 3 years on the Commission, at every opportunity to assure that atomic energy programs should be directed toward "strengthening free competition in private enterprise" under the policy contained in Section 1(a) of the Atomic Energy Act. I have been concerned over the fact that nationalization of the atomic energy industry, coupled with a policy of contracting out most operations, has permitted a very few to get an inside track on atomic energy "know-how." Therefore, one work close to my heart has been the promotion of a broader and fuller private participation in the industrial power program. Just as I am convinced that initially the Federal Government must sponsor and finance full-scale power reactor development, so I am equally convinced that such

(Continued on p. 56)

International Developments in

By J. A. GOEDKOOP
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THE PROGRESS of heavy water reactor technology and the prospects for heavy water power reactors were the main topics of discussion at the world's first open international meeting on nuclear energy. The meeting was held in Kjeller and Oslo, Norway, on August 11 to 13, this year.

Power Reactors?

The promising future of heavy water reactors depends on the moderate abundance of natural uranium and on the continued scarcity of plutonium and enriched fuel, according to L. Kowarski of France. The article below expresses his views in more detail.

Gunnar Randers (Jener) pointed out that enriched uranium and plutonium are available only to those countries whose projects have had military backgrounds. Hence, most nations are forced to use natural uranium. The most important argument for using heavy water as the moderator in natural uranium power reactors is that it allows sufficiently high burnup to make the electric generation economical. The possibility of structural alteration of the fuel elements suggests the consideration of homogeneous, circulating fuel reactors with continuous processing. This type, however, would involve problems.

A less optimistic forecast for heavy water power reactors was made by John V. Dunworth of England. The present high capital cost of a heavy water moderated power plant forces the use of liquid coolants. Water and sodium cooling cause too great a risk to the heavy water. Heavy water cooling would avoid the risk, but the piping holdup would increase the investment still further. The only foreseeable future for heavy water lies in its use for such special purposes as ship propulsion where—when using natural uranium—it would afford the only reasonably compact system.

Means of reducing the cost of heavy water were discussed by I. Dostrovsky of Israel. Except for the product from the electrolytic process used in Norway, the price of the heavy water is largely determined by the plant amortization. Since the plant size is inversely proportional to the deuterium concentration in the feed water, the very first step should be performed cheaply by biochemical means or by utilizing waste heat from other processes.

The Future of Heavy Water Reactors

Heavy water's superior moderating and neutron-economy characteristics give it an advantage over other moderators for use in natural uranium reactors. Despite its high cost, the use of heavy water is warranted because of the scarcity of enriched uranium and plutonium

By L. KOWARSKI
Commissariat à l'Energie Atomique
Paris, France

THE PROPERTIES OF HEAVY WATER that have made it useful in existing reactors will make substantial power-output improvements possible in future natural uranium reactors.

Heavy water is such an efficient and neutron-economizing moderator that its use in a reactor will allow the designer to provide for higher temperatures and greater heat removal than is possible with other moderators.

The extent of heavy water's usefulness can be seen by a consideration of its effect on a thermal reactor's multiplication factor as expressed by the formula in the box on the next page. The formula assumes no neutron leakage from the reactor and, hence, applies only to an infinitely large system. Appropriate geometry factors must be applied for the formula to apply to an actual reactor. The effective (after geometry correction) multiplication factor, k_{eff}, must equal unity (at least) to sustain the chain reaction.

The character of the fuel determines η and ϵ, but p and f can be varied to some extent by changes in other parts of the core. Although always less than unity, p and f should be as large as possible to insure the criticality of the reactor.

An ideal lattice of natural uranium and D_2O with a high degree of purity and some very rudimentary canning

Descriptions of Specific Reactors

It is interesting to note that the U. S. reactors described all used enriched uranium and the European reactors all used natural uranium.

CP-3'. In a paper prepared by Stuart McLain (U. S.) the CP-3' was described as operating at 275 kw and having an average thermal flux of 2×10^{12}.

CP-5. This new research reactor has an average thermal flux of 2×10^{13} at a power of 1 Mw. John West (U. S.) said that it contains 1.2 kg of U^{235} alloyed with aluminum. It is contained in a 183 cm diameter cylindrical tank filled with D_2O. Forcing D_2O through the spaces between the fuel element plates provides cooling.

If, after a shut-down, xenon has built-up so much that removing the control rods does not supply enough reactivity to achieve criticality, chilled water from an external tank may be introduced to obtain enough extra reactivity to permit the reactor to go critical.

The reactor building is designed to prevent the escape of fission product gases in the event of an accident.

Swedish. The first Swedish reactor is being built in an artificial cave in the city of Stockholm, according to Sigvard Eklund. It should be finished early in 1954. The reactor will be of the same type and rating as CP-3 and JEEP. It will produce about 0.1 Mw/ton of U.

Saclay. Kowarski described the Saclay (or P.2) reactor, and Jacques Bernot explained the details of its cooling system. The coolant is nitrogen under 10 atmospheres pressure. The reactor tank—which contains 6 tons of heavy water—is not pressurized as a whole. The coolant flows down through an outer jacket on each rod and up again through an inner jacket. It uses three tons of uranium. The designers had hoped to extract 1.5 Mw; but, only ⅔ of this power could be extracted with the present fuel element design. The fuel elements vibrated dangerously at this low power. Canning is being improved and 2 Mw may soon be extracted.

Swiss. The reactor being planned in Switzerland will be used for materials-testing, according to Werner Zunti, and will have extensive facilities for high-temperature in-pile experiments. It will have 5 tons of natural uranium and 11 tons of heavy water. It will be heavy-water cooled and will produce 10 Mw with a maximum thermal neutron flux of 2×10^{13}.

Dutch-Norwegian. The natural uranium, heavy water cooled and moderated power reactor being planned cooperatively by the Dutch and Norwegians was described by Odd Dahl of Norway. The reactor will generate 20

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gives a *pf* of about 0.92 and a *k* of about 1.25. A natural uranium and graphite lattice gives a *pf* of about 0.79 and a *k* of about 1.07. The *pf* product must be not lower than about 0.77 if unwieldiness is to be prevented. The margin is then, 0.15 in the case of heavy water, and only 0.02 for graphite. Although these figures have only a trend-indicating validity, they show that heavy water provides much more flexibility than graphite.

In these three figures—0.92, 0.79, and 0.77—lies the whole reason for the use of heavy water in reactors. This reason exists only when using natural uranium because only then can the still great expense (at present about $100 per lb) of using heavy water be justified.

It is interesting to consider the manner in which these particular advantages of heavy water have been, are, and will influence the decisions concerning the construction of reactors.

The distinction between past, present, and future implies rather fine terminological points. The past of heavy water reactors is the time when people wanted to build any type of chain-reacting system as quickly as possible. The present is the situation in which laboratory or material-testing

KEY FORMULA

$$k = \eta \epsilon p f$$

where

k = multiplication factor
= ratio of the number of thermal neutrons in one generation to the number in the preceding generation

η = average number of fast fission neutrons emitted as a result of the capture of one thermal neutron in the fuel material

ϵ = fast fission factor
= ratio of the total number of fast neutrons produced by fissions due to neutrons of all energies to the number resulting from thermal neutron fissions

p = resonance escape probability
= fraction of fast (fission) neutrons that escape capture while being slowed down

f = thermalization factor
= ratio of thermal neutrons absorbed in the fuel to the total number of thermal neutrons absorbed by fuel, moderator, and other materials in the reactor

to 25 Mw and will have 9 tons of uranium in aluminum canned elements with beryllium oxide jackets. It will use 11 tons of D_2O at 50° C and 35 atmospheres pressure. A 40 cm thick BeO reflector will be located inside a 15 cm thick steel tank. The inlet cooling water will be at 200° C and will exit at 230° C.

MTR. The description of this enriched uranium reactor was of considerable interest even though the reactor does not fall within the scope of the conference title.

This second paper by McLain noted that the design of the Materials Testing Reactor was largely dictated by the desire to have a large flux of uncollided neutrons. A virgin flux of 10^{14} (as compared with 10^{12} in the CP-5) is achieved by concentrating the fuel in a very small volume and by having very little moderation between the fuel elements. The core contains between 3 and 4 kg of U^{235}. Moderation and cooling is by light water. There is a beryllium reflector around the core and it is in the Be where the maximum thermal neutron flux (4×10^{14}) is achieved. The average thermal flux is 2×10^{14} at a power of 30 Mw. Unloading the reactor is accomplished through a canal that runs underneath.

HRE. The circulating fuel Homogeneous Reactor Experiment was described by A. M. Weinberg of the U. S. Temperature and power are very strongly coupled in this type reactor. When heat is removed from the fuel at the heat exchanger, the fuel returns to the reactor at a lower temperature and this causes the reactivity, and then the power, to go up. Within limits, the operating power is determined by the power extracted. But the temperature is determined by the control rod setting.

The HRE was the second reactor to produce electricity. It generated about 150 kilowatts of power.

Thermodynamic Technology

Nuclear technology, according to Weinberg, is basically a thermodynamic technology. This would have been more generally recognized if nuclear physicists had been less in evidence during its development. Drawing the analogy between the steam power plant, which uses an oxygen flame, and the nuclear plant, based on a neutron "flame"—detailed study of the neutron flame is bound to be progressively less important just as detailed study of the tensions and temperatures of the oxygen flame is of minor importance. Thermodynamic considerations must dominate if nuclear technology is to be successful.

Kinetics and Control

Arne Lundby described measurements he and N. Holt made of the response of the Kjeller JEEP to a sudden rise of reactivity. The sudden rise was effected by shooting out a piece of cadium. A method of measuring reactivity increments due to control rods, etc., while the pile is subcritical was described by Victor Raievski (France).

Heavy-Water Reactors

reactors are wanted with a high flux as quickly and as cheaply as possible. And the future is the time when heavy water will be used to extract useful energy from natural uranium.

The PAST

In 1939 it became obvious that heavy water would be useful in building a chain reacting system.

By permitting p and f to be kept at their maximums, it was possible to waste neutrons and still get along with relatively small quantities of the almost unobtainable uranium.

Heavy water moderators permitted inadequate chemistry and allowed the use of impure uranium, a not-so-pure graphite for the reflector, and even the heavy water itself did not have to be of the highest purity. Furthermore, the margin permitted the reactor designer to neglect the finer points of the theoretical physics involved. If graphite was used as the moderator the reactor had to be designed to have very nearly the optimum lattice configuration. Heavy water allowed considerable deviations from the elusive optimum.

In addition to imperfect chemistry and theoretical physics, engineering problems could be treated casually. The canning could be made with but little regard to nuclear considerations. Since the reactor structure was not too heavy, a few mistakes could be afforded.

The use of heavy water in the early days permitted the acquisition of data which had considerable importance in the whole wartime project and which has been useful in reactor development ever since.

Where there was a need, whether political, psychological, or scientific, to produce a chain reaction as quickly as possible, the supreme virtues of heavy water commended themselves. However, such situations are less likely to occur in the future, and it may be hoped that the time of digging up any kind of reactor, provided it reacts, is past.

The PRESENT

Heavy water reactors are operated today with a more exalted aim in view. High fluxes for physics, isotope-production and materials testing have been obtained quickly and cheaply.

Heavy water was chosen for existing reactors because it permits the use of a minimum amount of uranium; very high radiation fluxes are developed because of the small amount of fuel required to attain criticality; and heavy water's low absorption cross section permits more leeway in the design of a superior cooling system and in providing a larger quantity of better-equipped experimental holes.

The importance of improving the cooling system can be seen from the table on the next page.

[Although the BEPO and Brookhaven reactors are graphite moderated, the table is valid for heavy water because the effectiveness of the coolant is basically the same regardless of the moderator.]

There is no absolute correspondence between the thermal neutron flux in the center of a laboratory reactor and its heat extraction in kilowatts per ton; but, experience with existing piles indicates that a crude conversion can be made by putting one kw/ton of uranium approximately equal to 1.4×10^{10}

Non-linear reactor dynamics were discussed by Weinberg. Problems of this nature arise in reactors in which temperature and reactivity are so strongly coupled and power fluctuations are so fast that stability depends on the coupling rather than on the control rod systems. Starting from the basic equations

$$(d/dt) \log P = -(\alpha/\tau)\, T$$

and

$$dT/dt = \epsilon\,(P - P_e)$$

where P = power generated, P_e = power extracted, T = temperature above that at which the reactor is critical, t = time, τ = life time of neutrons, α = temperature coefficient of excess multiplication factor, and ϵ = reciprocal heat capacity, he analyzed the situations that arise with different kinds of cooling and how they affect the stability.

Shorter papers were presented by K. P. Lien (Norway) on the control mechanism of the JEEP, by W. Halg and V. O. Eriksen (Joint Establishment for Nuclear Research) on the xenon effect in JEEP, and by M. Bogaardt and M. Bustraan on thermal breeding in a JEEP-type reactor.

Neutron Physics

A diverse group of papers were presented on reactor neutron physics.

Kjeller. Neutron physics work being done at Kjeller was reviewed by Goedkoop. N. Holt discussed a mechanical neutron monochromator and J. Pelser described a time-of-flight spectrograph. Cross section measurements of uranium were described by D. Popovic. A. W. McReynolds and E. Andersen discussed neutron crystal spectrometer measurements on samarium. Centrifuge separation of isotopes was covered by H. Klepp.

England. A new fast chopper was described and measurements of pile spectra were explained by P. A. Egelstaff of Harwell. Cold neutron scattering experiments were also reviewed.

Netherlands. Slow neutron spectroscopy by filter methods was discussed by P. J. Pasma. The use of nuclear emulsions for fast neutron spectroscopy was described by P. M. Endt and C. H. Paris.

Canada. Recent gamma-ray studies at Chalk River were reported by B. B. Kinsey.

Belgium. A technique for absolute measurement of neutron sources in water was presented in a paper by G. C. Tavernier and A. Detroyer, who also reviewed the present state of world-wide source intercomparisons.

Sweden. A description of measurements of the decay of neutron intensity from a pulsed neutron source was made by Guy von Dardel. The pulses are caused by a burst of neutrons generated inside a block of moderator, e.g., a reactor mock-up.

International Society

A working committee was set up to prepare the organization of an international nuclear energy society.

The society, when formed, will organize information meetings, standardize symbols and notation, distribute information, and perhaps publish a periodical. END

neutrons/cm²/sec at the center of the reactor.

Both the heat extraction rate and the flux may be expected to increase as the metallurgy improves to permit higher temperatures and when the fuel element shapes are optimized. In spite of this progress, the competition of enriched uranium in conjunction with ordinary water may become too strong for the continued use of heavy water and natural uranium in laboratory reactors.

Geometrical Progression of Coolant Efficiency

Heat developed by natural U, (kw/ton)*	*Coolant*	*Examples*
100	Circulating D_2O	CP-3, JEEP
320	Low pressure gas	BEPO, Brookhaven
1,000	High pressure gas	Possible variants of the Saclay reactor
3,200	Water	NRX
10,000	Sodium	Pac. Gas-Bechtel Proposal

* Denotes the entire energy from fission—not only the heat carried away by the coolant. The difference is about 10%. The metric ton is used here and is about 10% bigger than the short ton. The kw/ton figures given here are about 20% higher than if the short ton and thermal extraction rate were used. The approximate figures given in this column are arranged in a geometrical progression.

The FUTURE

In reactors planned for the future, it is no longer as desirable to get the maximum kilowatts per ton from as few tons as possible. Sheer kilowatts are now wanted without concern for whether they come from power-only reactors or from dual-purpose reactors.

Here again there is a future for heavy water, but only providing there is no great abundance of either natural uranium or pure fissile material, or both of these.

If natural uranium is extremely abundant and cheap, nobody would go to the length of building reactors with as expensive an ingredient as heavy water just to obtain many kilowatts per ton. Everyone would build enormous graphite piles without trying to push the flux or the heat extraction rate very high. The burn-up allowed would be comparatively low. But what would it matter if uranium is practically free? There would be no incentive for a very efficient nuclear technology and, hence, there would be no incentive for using a moderator as efficient and expensive as heavy water.

If natural uranium is not so exceedingly cheap but breeding is very easy and efficient, then again there would be no future for heavy water because power would be obtained either in breeders or in secondary reactors burning pure fissile material. Both would presumably run with fast or medium-fast neutrons and there would be no need for a moderator.

If natural uranium is reasonably accessible, yet bred materials are fairly expensive, then there is a definite in-

centive for burning natural uranium and for burning it efficiently.

This last situation is precisely the one that the world finds itself in at present. Breeding techniques are progressing but economic breeding is still a matter of an uncertain future; natural uranium is becoming more plentiful, but it is still far from being so cheap that it can be wasted in a multitude of inefficient reactors.

Although interest is very strong in the breeding prospect, natural uranium is still important as a source of power. In this situation heavy water comes into its own because a good neutron economy is important. Unlike graphite or light water, heavy water absorbs few neutrons and therefore does not waste fissile uranium-235, which is still a precious natural resource even in its naturally diluted state.

The numerical margin of k offered by heavy water permits the inclusion of many desirable design features according to the designer's requirements.

In the laboratory reactors, one way of using this margin was to keep pf as high as possible and to throw neutrons away by allowing surface leakage. In this way uranium inventory could be kept low.

Increase Power Output

Now power is wanted—plenty of kilowatts per ton—but also plenty of tons. There is no longer any incentive for using very high values of pf, and the lattice can be changed to increase power output. This device of deliberate spoiling can yield important results. There are various ways of spoiling a lattice constructively.

Use Better Coolant

First of all, f can be spoiled. There is no longer any reason to spoil it by using impure ingredients. There is now a sufficient margin in k that a more neutron absorbing coolant can be used to improve the extraction of heat. Heavy water reactors can be cooled by sodium; but graphite reactors do not have a sufficient margin in k to permit the spoiling of f.

Improve Structure

The margin in f of heavy water reactors may also permit the use of thick or neutron-absorbing materials for cooling channels or structure. Aluminum (or its alloys), which nobody likes, but which must be used as long as there is no margin, may be eliminated from the structure.

Increase Burnup

The margin in f may also allow the fuel elements to be left in the reactor for a long time in spite of the accumulating poisons (unless the elements suffer metallurgical damage first).

There is also a margin in p. The spoiling of p is much more satisfactory to the soul than the spoiling of f. When f is spoiled the neutrons are lost, whereas the spoiling of p means simply that more plutonium is made. Incidentally, even a small increase in the plutonium production rate may reverse the effects of poisoning, and a higher burnup may thus be obtained than in a graphite reactor.

Use More Fuel

More uranium provides more kilowatts for the same price in heavy water. The margin in p may permit putting an amount of uranium in the lattice much higher than the optimum which gives the highest k. The optimum lattice for the highest k contains about 4 weight units of uranium for 10 of heavy water, which is something like 40%. But if it is desired to use a lot of uranium, then by putting in 100%, or possibly 200%, the lattice is spoiled satisfactorily and usefully. The present ratios of uranium to heavy water are of the order of 1 to 1. The ratio is much nearer 2 to 1 in the reactor proposed by PG & E and Bechtel which would contain something like 60 short tons of uranium for about 33 short tons of heavy water.

Adjust Fuel Element Shape

Another method of utilizing the margin in p involves diminishing the degree of segregation.

A high value of p is usually obtained by putting the uranium into shapes which offered a maximum volume with a minimum surface. This excludes the homogeneous distribution of uranium and leads to its use in lumps or rods.

This technique is in direct contradiction with the best conditions for heat extraction. To improve the cooling characteristics, much thinner rods than those required for the optimum lattice should be used. In some recent projects, the temperature of uranium inside the rods gets quite dangerously close to its phase transformation point at 660° C. It may be noticed that all the thermal reactor designs presented to the AEC by the industrial study teams were well below this temperature. It seems, then, that there is something to be said for spoiling p by using extra thin rods in which there is little difference between the surface and the central temperature.

Another way to improve cooling involves using plane-shaped elements instead of rods. Geometrically speaking, locating fuel on centers provides a three-dimensional segregation, rods a two-dimensional one, and planes a three-dimensional one. Full benefit from the segregation is not derived when using plane-shaped elements and p is not as high as it could be. But since the maximum amount of heat cannot be extracted without infringing on the principle of the most efficient segregation, fuel plates instead of fuel lumps or rods would be a useful way of using the margin in p. This means that instead of forcing the heat to travel along a radius of the order of ½ in. or more, there would be a much shorter road across the uranium mass. The rods could be planes in the form of corrugated surfaces or even thin rods put very closely side by side.

Heavy water offers a fertile field for the designer's skill and ingenuity in that nuclear considerations do not prevent him from trying to improve the reactor's coolant circuit or including other desirable features. Graphite's small margin in k does not permit any of these improvements.

It is interesting to note that there is practically no competition in the recent industrial proposals between heavy water and graphite in working with natural uranium. Graphite reappears, however, in connection with enriched fuel.

Conclusion

Since the present-day abundance ratio between natural uranium and pure fissile material seems to favor the use of the former, it is reasonably evident that heavy water has a considerable future as long as this situation continues. How long this will be depends on the speed with which breeding is developed and operated. Meanwhile, there is a good chance of heavy water successfully sustaining its competition with graphite (or ordinary water) used in conjunction with enriched fuel.

(*Continued on page 23*)

Ionization-Chamber Device for Clinical Gamma-Ray Use

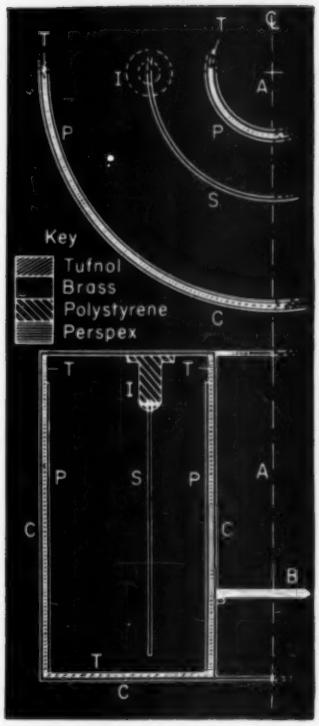

FIG. 1. Construction of ionization chambers (simplified)

For routine clinical sample measurements, ionization chambers in conjunction with an electrostatic indicator provide an easily maintained system. It is satisfactory for iodine-131 measurements in the range 20 μc to 400 mc

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DEVICES AVAILABLE for measuring the therapeutic or diagnostic amounts of radioactive materials handled in hospital departments include G-M and scintillation counters and ionization chambers. Sinclair (*1*) has compared the G-M counter and ion-chamber systems of γ-measurement. Though G-M and scintillation instruments have wide application (*2, 3*), especially for small activities, many such measurements are best carried out by γ-ray ionization chambers, since these are more simple and robust, and are therefore more suitable for routine use. The equipment described in this article has been developed for such routine clinical γ-measurements as:

1. Checking activities of isotope shipments, within the range 1–400 mc.

2. Measuring activities of "doses" for administration to patients, from 20 μc upwards.

3. Measuring activities of urine samples, from 20 μc upwards.

Ionization-chamber Specifications

	Small chamber	*Large chamber*
Over-all diameter (cm)	16	39
Over-all depth (cm)	10	61
Source cavity		
Diameter (cm)	5.5	15
Depth (cm)	10	61
Effective volume (liters)	1.5	55
Capacity ($\mu\mu$f)	30	120

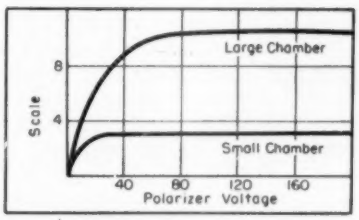

FIG. 2. Saturation curves of chambers (100-mc radium source)

4. Comparison of activities of solid sources (e.g., Co^{60} and radium needles), within the range 0.1–50 mc.

The equipment consists of two ionization chambers, a chamber and range selector, an electrostatic indicator, and a power unit.

The principle of operation is conventional. The saturation current of either chamber is passed through one of a range of suitable resistors, and the resulting voltage is measured by the electrostatic instrument.

Ionization Chambers

Two air-filled, atmospheric-pressure, cylindrical ionization chambers are used. In each, an annular air volume surrounds a cylindrical source cavity. Their construction is a development of that described by Sinclair and Newberry (*4*) and is shown in Fig. 1. Specifications are given in the table on this page.

The rigid brass outer casing (*C*) is

grounded and acts as guard-ring, carrying the signal electrode (*S*) on polystyrene pillars (*I*). Two polarizing electrodes (*P*) (connected together) form the inner and outer walls of the air-volume, and are insulated from the outer casing by $\frac{1}{16}$-in. Tufnol sheet (*T*). All electrodes are made of 20 s.w.g. brass sheet. In both chambers, the source cavity (*A*) is long in relation to the size of samples to be measured therein, a removable shelf (*B*) holding sources near the chamber center. This arrangement, together with absence of sensitive volume beneath the source, insures small change of response with source volume. The signal electrode is mounted asymmetrically, thus roughly matching the collecting field to the average γ-intensity in each half of the air-volume and insuring that both halves saturate together.

The small chamber is intended for small, highly active samples, and is surrounded by a lead shield, giving 3 mr/hr at $\frac{1}{2}$ meter from 100 mc I^{131} within the chamber.

The unshielded, large chamber can accommodate Winchester quart bottles of active urine or doses of large volume, such as colloidal Au^{198} for intraperitoneal injection.

A polarizing voltage of 200 is used for both chambers (Fig. 2). Any fluctuation of this voltage causes a corresponding (small) change in electrometer reading, due to capacitive coupling between the chamber electrodes. The polarizing voltage is therefore roughly stabilized. Persisting small variations of electrometer reading were traced to changes in polarizer voltage caused by fluctuations of the Tufnol leakage current, the polarizer being supplied via a high-resistance filter. Assuming the cause to be moisture content of the Tufnol, P.V.C. sheet should prove a better material.

For both chambers, a series of locating holders provides constant geometry for the range of bottles and flasks encountered in routine clinical work.

Range Selector

To cover a wide activity range, it must be possible to select from a suitable range of resistors. A unit accommodating up to 8 resistors, in addition to a grounding position, was designed for high insulation and lowest possible capacity. It also embodies a chamber-selector switch, and is used with both chambers. Magnetic actuation was chosen, eliminating supporting insulators for the resistors, which move bodily when switched into circuit.

Basic construction of the unit is shown in Fig. 3. The concentric input socket (*S*) of the unit carries a small platinum contact ring (*C*). The resistors (*R*) are all of glass-sealed, silicone-coated construction and are mounted radially to this ring, being clamped and electrically connected at their outer (grounded) ends to beryllium-copper springstrips (*B*), which are anchored and grounded at their outer ends. These springstrips also carry on their undersides short Stalloy strips (*D*). The free lead of each resistor carries a small platinum wire (*W*), which can contact the fixed ring (*C*). The selector knob rotates a small Ticonal horseshoe magnet (*M*) over the Stalloy strips, the magnet arm (*A*) being supported rigidly by a roller (*P*) running on a rail (*Q*). On the magnet arm is mounted a stop-rod (*T*), which limits the upward excursion of the springstrips when selected, thus providing a small air gap in the magnetic circuit, and preventing "sticking." Thus, at any position of the selector knob, only the appropriate resistor contacts the ring (*C*) and is in circuit.

Figure 4 shows the complete unit with some of the resistors absent for clarity. The right-hand of the two arrowed resistors is selected, and its platinum wire is contacting the ring (*C*). The grounding contact (*E*), dessicator holder (*H*), and the shaft (*F*) of the chamber selector switch can also be seen.

Electrostatic Indicator

Electrometers available include Dolezalek, Compton, Lindemann, and quartz-fiber (*5*) types. The instrument employed* is a modified Dolezalek quadrant electrometer used heterostatically as an electrostatic voltmeter. Its advantages over a high-input-impedance, d-c amplifier, include:

1. Lower dependence on supply voltages, and therefore very low drift.
2. Greater simplicity, and therefore less likelihood of fault.
3. Less maintenance.
4. Greater scale length.

Its disadvantages include:

1. No "transportability."
2. Lower sensitivity than d-c amplifier.
3. Higher capacity, and therefore longer response-time.

The moving vane, which carries a mirror, is suspended by two opposed

* An experimental model made by Cambridge Instrument Co. Ltd., England, made available by the kindness of Dr. M. C. Marsh.

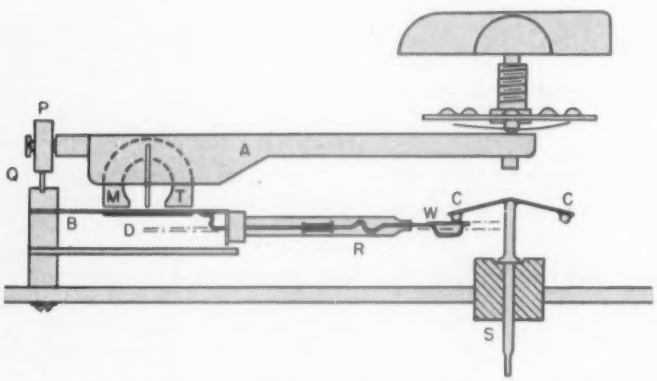

FIG. 3. Construction of range-selector (*T* is stop-rod between magnet poles)

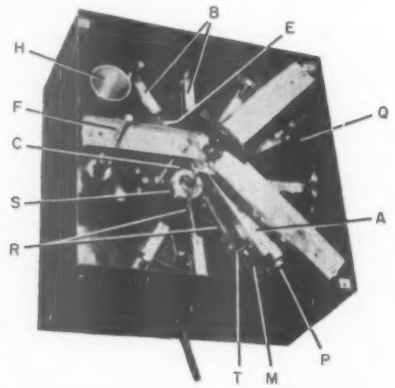

FIG. 4. Internal view of range selector

phosphor-bronze fibers and rotates inside two pairs of hollow cross-connected conducting quadrants. One quadrant-pair is grounded; the other highly insulated pair carries the signal voltage.

The electrometer and optical system are assembled in a "spot-galvanometer" case, giving a scale length of 16 cm.

When correctly set up, the voltage response of the instrument is satisfactorily linear (Fig. 5), full-scale deflection being given by approximately 14 volts.

Such linearity, however, depends critically on level and on correct adjustment of the torsion of both top and bottom fibers. In general, for a particular setting of the leveling screws, there is one unique setting of the two fiber adjusters that gives coincidence of the electrical, mechanical, and scale zeroes, with linearity of response. The need for careful setting up precludes portability; the whole equipment is, however, a fixed installation, and so setting up is only required initially, and is, moreover, much less tedious than that required by a Compton electrometer.

The sensitivity of the instrument varies with vane voltage (Fig. 6) in approximately parabolic manner; thus, at maximum sensitivity, the effect of changes in this voltage is small.

There is some change of sensitivity and zero with ambient temperature. A sensitive zero adjuster has been provided, and experiments over many temperature cycles have shown (over a temperature range of 30° F) a maximum sensitivity variation of $\pm$ 1.5%.

Input resistance and capacity of the electrometer are 10^{16} ohms and 30 $\mu\mu$f.

Performance of the Equipment

So far, solutions of I^{131}, Na^{24}, Au^{198}, Fe^{59}, solid Co^{60}, and radium sources have been measured. In all cases, there is preliminary calibration with known sources, this being satisfactorily linear (Fig. 7). Iodine-131 can be measured within the range 20 μc to 400 mc, the lower limit set by increasing response time. Similar ranges are covered for other isotopes. Resistors in present use range from 10^9 to 5×10^{11} ohms, the latter giving a response time-constant of approximately 100 sec.

Variation in volume of an active solution gives rise to variations of absorption, scatter, and geometry (*6, 7*), which can affect response. In this equipment, the effect is small, and varies slightly with γ-energy, as seen in Fig. 8.

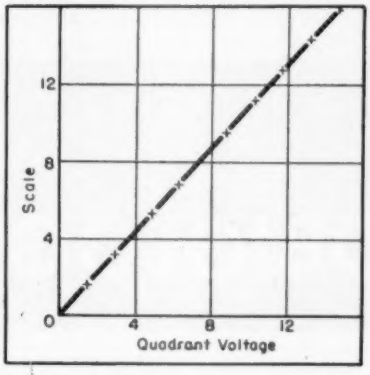

FIG. 5. Quadrant voltage response of electrometer (constant vane voltage)

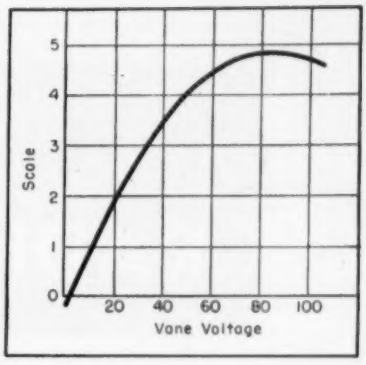

FIG. 6. Variation of electrometer sensitivity with vane voltage (constant quadrant voltage)

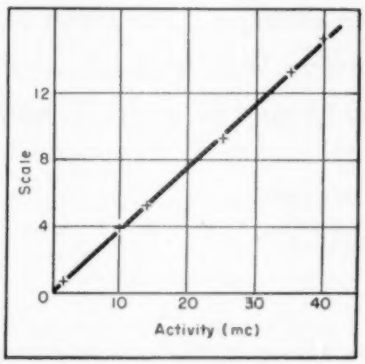

FIG. 7. Typical I^{131} activity calibration of one range

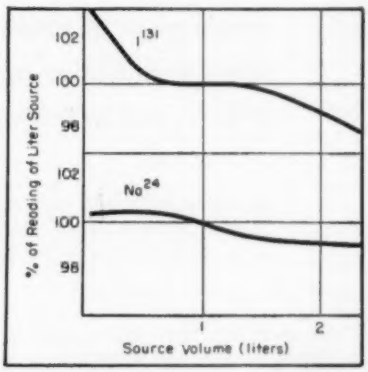

FIG. 8. Variation of response with source volume (constant activity, reading of liter source taken arbitrarily as 100%)

Comments

Two types of development of this equipment are possible.

Sensitivity. If the existing chambers were used with a more sensitive (and more costly) indicator, such as a vibrating-reed amplifier (*8–10*), it should easily be possible to measure 0.1 μc I^{131}. Further improvement would result from argon-filled, high-pressure ionization chambers and lead-lined electrodes.

Response time. It is possible to organize work so that the long response time is not inconvenient. However, if a rapid response is desired, this can be achieved by suitable feedback circuitry, employing a simple supplementary electronic amplifier. Work is proceeding in this direction.

* * *

The author wishes to thank the Cambridge Instrument Co. Ltd. for making available the experimental electrometer, T. S. Marshall and workshop technicians for constructing the chambers, L. A. Daynes for diagrams and for constructing the range selector, and H. F. Freundlich, Principal Physicist, for initiating the work and for his continual help and encouragement.

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Current Research in

RADIOBIOLOGY

Study of factors that modify radiation effects in biological and chemical systems may lead to better understanding of the fundamental mechanism of radiation damage. The status of international work in radiation protection, DNA synthesis, and radiosensitivity is surveyed in this report based on a recent conference

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MANY ASPECTS of the action of ionizing radiation on cells and organisms and on chemical systems whose response may guide the interpretation of biological effects were covered at the conference on radiobiology in Aarhus, Denmark, July 16–18, 1953, under the chairmanship of Prof. Carl Krebs. The major interest centered around those factors that modify the effects of radiation. The study of these modifying factors at the chemical level throws some light on the mechanism of the initial action of the radiation, and attempts were made to clarify some of the fundamental issues arising in this connection.

Progress was also reported on the protection of higher animals against radiation damage. Other main fields discussed were the carcinogenic action of radiation, the effect of irradiation on synthesis of deoxyribonucleic acid (DNA), and the influence on radiosensitivity of biological variables.

PHYSICS OF EFFECTS IN LIQUID SYSTEMS

The effect of ionizing radiations in liquids (*U. Fano*, Washington) is primarily the same as that in gases, i.e., ionization and excitation of molecules. But to understand the mechanism of energy dissipation in liquids, we must rely on data furnished by radiation chemistry, an experimental field in which nonreproducibility of results shows that there are still some unknown and uncontrolled factors.

It is, however, generally accepted that the energy from ionizing radiations is absorbed along the tracks of the particle, giving a column of positive ions surrounded by a negative ion sheath. The characteristics of this column will be determined by the time taken for the capture of secondary electrons, by diffusion constants, and other physical factors. Ions will dissociate, in times of the order of 10^{-12} sec, into highly excited radicals that will diffuse out of the column and may lead to excitation of solvent molecules and to reactions involving them and solute molecules. It is thought that these processes may take up to 10^{-4} sec, but even much shorter times for the relaxation and reorganization of excited or ionized species would suffice to break H-bonds and thus cause the break-up of the molecule in which the energy is actually absorbed.

COMPARISON OF DIFFERENT RADIATIONS

The effect of O_2 tension on radiosensitivity was described for a number of chemical and biological systems. *M. Ebert* (London) described experiments on the reduction of O_2 to H_2O_2 in water by 1-Mev electrons. When mixtures of O_2 and N_2 were bubbled through the solution during irradiation, the initial yield of H_2O_2 was independent of O_2 concentration. [The different results previously obtained by Bonet-Maury (*1*) may be due to the different quality of radiation used.] The O_2 concentration did, however, influence the equilibrium values for H_2O_2 yield, indicating that decomposition of H_2O_2 brought about by irradiation is greatly influenced by dissolved molecular oxygen. When water of *p*H 5.5–7.5 was irradiated, the equilibrium values were found to be proportional to O_2 concentration in the bubbling gas.

A further chemical example is given by the loss of viscosity of polymethacrylate (PMA) after irradiation (*Z. M. Bacq*, Liege, in collaboration with *P. Alexander*, London). PMA is apparently insensitive to OH radicals

and is not attacked in the absence of O_2; as O_2 concentration is increased to 21%, loss of viscosity increases rapidly; higher O_2 concentrations do not measurably increase the effect. *J. A. V. Butler* (London) (*2*) and *G. Scholes* (Newcastle) *et al.* (*3, 4*) have shown that the viscosity of DNA solutions decreases continuously for 30 hr after the end of irradiation, and that this decrease is greatly enhanced if the irradiation is carried out in the presence of O_2.

The inactivation of bacteriophage S13 by irradiation in dilute aqueous suspension [*T. Alper*, London (*5*)] appears to be due to H radicals. The presence of O_2 during irradiation exerts an initial protective effect by competing for H radicals. Later, however, the H_2O_2 formed by irradiation in the presence of O_2 causes inactivation. Since irradiation sensitizes phage to H_2O_2 ("part-inactivation") the final effect of irradiation in O_2 may be greater than that of irradiation in N_2.

Fano pointed out that from a consideration of recent work [Gray (*6*)], it appears that a concentration of oxygen of about 1 molecule per 10^6 water molecules is critical in its effect on radiosensitivity. An increase of oxygen above this level does not usually substantially increase the chemical or biological effect of radiation. The activity of oxygen is attributed to the radical HO_2 formed by the H radical plus molecular oxygen. It thus seems likely that the lifetime of the H radical is at least 10^6 collisions.

The relationship between oxygen tension and the chemical effect of radiation is illustrated by the oxidation of Fe^{++} to Fe^{+++} in 0.8*N* H_2SO_4 [Ebert (*7*)]. An increase of oxygen tension from 0% to 8% results in a 2.5-fold increase in the initial yield of Fe^{+++}; further increase in O_2 from 8% to 100% increases the yield only to 2.7-fold.

A. D. Conger [London, in collaboration with *L. H. Gray* (*7*)] reported that when suspensions of Ehrlich ascites tumor cells are irradiated *in vitro* under various O_2 tensions, and the abnormal anaphases counted 24 hr after reinoculation into mice, the curve relating damage to O_2 tension is of the same shape as that found for a number of other radiation effects. He found a sharp increase between 0% and 20% oxygen, but only a slight rise between 20% and 100%. The over-all factor due to O_2 was about 3.5. For killing the tumor cells, the relative effectiveness of X-rays in air or pure O_2 compared with N_2 was about 3. The effect of O_2 tension on sensitivity to neutrons was very slight.

O. C. A. Scott [London, in collaboration with *L. H. Gray* (*7*)], has used Ehrlich mouse ascites tumor implanted intramuscularly (i.e., growing as a solid tumor) in mice, and irradiated the tumor while the mice were breathing pure O_2. Caliper measurements of the subsequent growth of the tumor showed that 1,000 r given when the mouse breathed O_2 for 15 min before and during irradiation had approximately the same effect on tumor growth as 1,500 r given when the mouse was breathing air. In experiments in which the mice breathed O_2 at 3 atmospheres, a somewhat larger increase in radiosensitivity was observed. The influence of O_2 on tumor response was much more marked with small tumors than with large.

Attention has been drawn by L. H. Gray to the fact that, since radiosensitivity rises steeply with O_2 tension at low tensions but becomes independent at higher tensions, a general raising of O_2 tension throughout an organism should result in an increase in the sensitivity to X-rays of partially anoxic tissues relative to those normally well supplied with O_2. There are reasons for believing that zones of partial anoxia exist in some human tumors. Scott's experiments show that the response of a particular animal tumor can be enhanced in the manner expected. This effect seems to be a differential one, since the damage to normal tissue, as judged by epilation and skin reaction, was not increased by so large a factor as that to the tumor. The indications are strong, therefore, that the increased radiosensitivity is in fact due to increased O_2 tension in the tumor tissue. The experiments call for a much fuller consideration of O_2 tension as a factor in clinical radiotherapy.

Oxygen Tension within Cell

M. Ebert suggested that the Fe^{++} system shows a striking resemblance to the biological systems described previously. The oxidation yield was proportional to dose for each gas mixture studied, which allows extrapolation to the low total doses of a few hundred roentgens used in biology. This would lead to the conclusion that the O_2 concentration inside a living cell is of the same order as in the surrounding medium.

If, however, H_2O_2 formation is taken as a model system, the picture is different. The initial ionic yield for H_2O_2 formation seems to be independent of O_2 concentration, and only the equilibrium values are influenced by the amount of O_2 available. To achieve a ratio of 3:1 in the radiation effect, such as is seen in biological experiments, the equilibrium values have to be reached with a few hundred roentgens. This leads to the assumption that the actual amount of free molecular O_2 available for radiation chemical reactions at the site of damage inside a cell at any given time should not exceed approximately one thousandth of the O_2 concentration in the surrounding fluids.

Lindeström-Lang (Copenhagen) believes that the concentration of free molecular O_2 inside a cell is likely to be smaller than 5×10^{-8} *M*. *H. Laser* (Cambridge) pointed out that the O_2 consumption due to normal enzymatic activity of a cell is independent of the external O_2 tension over a wide range. There seems to be a possibility that the cell allows only that amount of O_2 to enter which its enzymes will use at once. No direct experimental evidence about the free molecular O_2 concentration inside a living cell is available.

COMPARISON OF DIFFERENT RADIATIONS

The relative biological efficiency (RBE) of neutrons compared with X- or γ-rays has been determined for a number of biological effects. In reducing the height of barley plants arising from irradiated seed [*L. Ehrenberg*, Stockholm (*8*)], the n/X RBE was about 10. Several conditions of irradiation (O_2 tension, humidity, water content of the embryo, presence of H_2S) affected X-ray damage but were without influence on neutron-produced damage. The n/γ RBE for causing infertility in mice (*J. F. Loutit*, quoting *G. J. Neary*, Harwell), was 3 to 5; for the LD-50 of mice by whole-body irradiation, *T. Evans* [Iowa (*9*)] found an n/X RBE of about 8. The lens is especially sensitive to neutrons (RBE for mice more than 12). *A. Conger* pointed out that the RBE may depend on O_2 tension during irradiation;

when Ehrlich ascites tumor cells were irradiated *in vitro* and their subsequent growth measured, the n/X RBE was 6 when irradiation was in N_2, but only 2.5 to 2 when irradiation was in O_2. Fractionation of dose may also affect the RBE (*T. Evans* for cataract formation in mice).

For killing haploid yeast (*A. C. Birge*, California) a maximum effect on the cell appears to be produced by polonium α-particles. A further increase in ion density, using accelerated carbon nuclei, gave much less effect.

P. Bonet-Maury (Paris) reported results suggesting a qualitative difference between 200-kv X-rays and fast neutrons in affecting survival time of mice. With low doses neutrons are more effective, but with higher doses less effective, than X-rays. It seems to the present authors that this may be concerned with a different mechanism of death resulting from the two types of radiation.

For reduction in plant growth (*L. Ehrenberg*) and for H_2O_2 formation in water (*M. Ebert*), RBE increases with increasing ion density when comparisons are made in the range between high-energy electrons and X-rays, on the one hand, and 200-kv X-rays or lower, on the other.

T. Evans suggests from his measurements of RBE and from the relative irreversibility of neutron damage in the lens, that neutrons affect all irradiated cells while X-rays damage only those that are in a sensitive stage when irradiated. Ehrenberg's conclusions are somewhat similar. Both regard damage by neutrons as chiefly nuclear and irreversible, while at least part of the X-ray damage affects physiological processes in the cytoplasm and is influenced by the metabolic state of the cell during and after irradiation.

Fractionation of Dose

The LD-50 dose of X-rays for the Rhesus monkey and for mice (*Edith Paterson*, Manchester) is about 50% higher if irradiation is given in two sessions separated by 20 days instead of in a single session.

PROTECTION AND RECOVERY

Most of the substances that reduce the damage inflicted by radiation on chemical or biological systems can be described as scavengers, since they apparently protect against the initial radiation lesion by competing for radiation-produced radicals. A few agents that reduce damage are more properly described as recovery factors, since they help the organism to repair more quickly or more completely the lesions produced by radiation.

The scavenger type have no effect if introduced even a short time after irradiation. MEA (discussed later) is one of the few protective chemicals whose introduction after irradiation is claimed to lead to improved recovery and survival, and which may thus behave more nearly like those tissues and tissue extracts that help the organism to survive or repair the initial lesion.

Protection

In protecting polymethacrylate from depolymerization by X-rays (*Bacq*, in collaboration with *Alexander*) the best of a number of effective chemicals were found to be chelating agents (e.g. 8-hydroxyquinoline, dithiooxamide, sodium diethyl-dithiocarbamate). A few of these, notably the latter, were found to be very effective in tests on the survival of mice. Bacq pointed out that after irradiation *in vitro*, enzyme systems show decreased activity, whereas after irradiation *in vivo* they frequently show increased activity. He concludes from this that chemical protectors act by protecting a restorative factor for biochemical processes.

When mice are irradiated while breathing air containing CO or H_2S (*P. Bonet-Maury*) they survive larger X-ray doses than air controls. This is thought to be due to anoxia caused by blockage of O_2 transport to the tissues.

In view of the great effect of O_2 tension on radiosensitivity, the question arises whether all chemicals that protect biological systems when present at the time of irradiation may not do so by creating a relative anoxia. In some cases, e.g. cysteine, it appears at least possible that this may be so. *A. Hollaender*, quoting P. Salerno and H. Friedell, stated that injection of cysteine into dogs lowers the O_2 tension in venous blood. If O_2 is given during irradiation, the protective effect of cysteine is negated. Results indicating a similar situation were obtained by Sheldon, Wolf and K. Sax (quoted by Hollaender) with $Na_2S_2O_4$ in bean roots. If control and treated roots were irradiated in the absence of O_2, this substance had no protective action, indicating that it acts by removal of O_2. Å. Forssberg and N. Nybom (*10*) have reported that cysteine and anoxia are not additive in their protective effects on onion roots. Further, many substances that protect against X-rays are ineffective against neutrons or α-particles, with which O_2 tension is known to be unimportant. In the case of MEA (discussed later), however, Bacq believes that anoxia is not involved, since MEA does not interfere with O_2 transport.

Carbon Monoxide

It is known from the work of King *et al.* (*11*) that if Tradescantia microspores are X-irradiated in 1 atmosphere of CO plus 5 atmospheres of air, the number of dicentric and ring chromosomes is increased by 60–70% compared with irradiation in 1 atmosphere of air plus 5 atmospheres of N_2. CO alone gave only a slight increase over control values. *L. H. Gray* (*6*) (quoted by *M. Ebert*) irradiated bean roots under 50 atmospheres of CO plus 1 atmosphere of air, and found an increase of damage of 80%, judged by growth rate, compared with 50 atmospheres of air. When CO was present for 30 min before irradiation, the increase in damage was greater than if it was present for shorter periods. This suggests that CO acts in part biochemically. The same experiment with neutrons showed an insignificant increase in radiosensitivity due to CO. CO alone, in the absence of air, gave an effect approximating that of nitrogen, i.e., protection.

M. Ebert has found that CO in the absence of O_2 completely protects $FeSO_4$ in $0.8N$ H_2SO_4 from oxidation by radiation. In the presence of O_2 plus higher pressures of CO, the oxidation yield was much higher than in air alone. Other organic substances (ethyl alcohol, formaldehyde, oxalic acid, methyl alcohol) if present at more than 10^{-7} M, had an effect similar to that of CO. The increase in ferric yield was approximately two-fold if the substances were present at 10^{-2} M concentrations in the presence of O_2.

King *et al.* interpreted their results as due to a blocking of terminal oxidases leading to an accumulation of the damaging agent H_2O_2. Gray suggests a radiation chemical approach. CO dissolved in water is changed by radiation to HCHO (*12*), which is highly toxic and shows mutagenic ac-

tivity (*13*). This interpretation of the action of CO explains also the lack of CO effect on radiosensitivity to neutrons.

Cysteine

When onion roots are irradiated in water containing cysteine [*Å. Forssberg*, Stockholm (*10*)], the number of chromosome fragments appearing after 1, 2 and 3 days is about ⅔ less than that seen in cysteine-free controls. Cysteine also resulted in a quicker return to normal of the mitotic index and a less steep drop in growth rate of the roots.

Sheldon Wolf and *Sax* (quoted by *A. Hollaender*) have found that cysteine and BAL are good protectors against chromosome breakage by X-rays in bean roots. Cysteine does not, however, reduce the inhibition of P^{32} incorporation in DNA in mouse liver after X-rays (*L. Kelly*, California).

MEA

MEA (β-mercaptoethylamine) protects the livers of rats if injected before whole-body X-irradiation (*Van Lancker*, Louvain). A smaller but definite protective effect was found if MEA was injected after irradiation, but only if the liver was shielded. Using injections of S^{35}-labelled MEA, van Lancker showed that liver protection, either by shielding or by previous injection of MEA, increased the retention of MEA in the liver, but not the retention in bone marrow.

Cobalt (10γ) injected before irradiation has a very slight protective effect, but a marked effect if combined with liver shielding. This effect is less if cobalt is injected after irradiation.

Physical shielding of the liver during irradiation markedly increases the survival of rats, and bone marrow and spleen regenerate better if the liver is shielded than if they are themselves shielded. At the same time the liver, if irradiated locally, is very radioresistant and suffers no lesions after a much higher dose than that which produces liver lesions if given to the whole body.

When various organs of the rat, especially active bone marrow, are protected during otherwise whole-body irradiation, and loss of weight is measured (*L. F. Lamerton*, London), no effect is found on the immediate weight loss that follows irradiation, but the second weight loss, which occurs 9–12 days after irradiation, is reduced. With injection of MEA in nearly lethal doses, Lamerton found a reduction in both weight losses and in anemia.

MEA has been found not to reduce the rate of dominant lethal mutations in mice (*Loutit*, quoting *M. Lyon*, Edinburgh). It is of interest here that Russell *et al.* (*14*) found no protective effect of anoxia on this parameter, and suggest that the testis may normally be relatively anoxic.

Recovery: Tissues and Extracts

It is known that injection of spleen and bone marrow homogenates improve recovery from radiation damage (*15, 16*). *J. F. Loutit* (Harwell) stated that in his laboratory improved recovery was observed only when living cells are injected. *V. P. Bond* (California) reported that extracts of splenic material were effective after ribonuclease treatment but not after desoxyribonuclease treatment. Spleen extracts were much more effective in mice than rats, the latter showing more early deaths. This observation was confirmed by Loutit, who pointed out that irradiation produces a greater disturbance in water and electrolyte balance in rats than in mice. It is probably significant that spleen and bone marrow extracts improve recovery of marrow but not of the gastrointestinal tract.

To reduce the effects of haemopoetic damage by irradiation, *Cronkite* has attempted to maintain a normal white blood cell count in irradiated dogs by transfusion of freshly-separated white blood cells. In the most successful experiments, only 40% of the transfused cells remained in the circulation. There were indications that the surviving cells functioned normally, and that lymph nodes may take part in the rapid removal of transfused cells.

A. Hollaender (Oak Ridge) and his co-workers have attempted to isolate and identify the factor in tissue extracts that is responsible for the improved recovery of bacteria. By water extraction of tissues, precipitation by lead acetate, and chromatography, a factor was obtained that is effective in very small quantities. It is soluble in acid, butanol, and ethanol, is relatively heat resistant, retains its activity after a few days in a refrigerator, and has a molecular weight of approximately 20,000 to 40,000. It is not any of the known enzymes or amino acids, nor nucleic acid. It is effective against X-ray damage but not against ultraviolet damage. Yeast was found to be a good source of the factor. Among mammalian tissues, liver was not as good a source as spleen. The factor cannot be recovered from irradiated spleen. Hollaender believes that the same factor is recovered from yeast as from mammalian tissues.

The radiation damage suffered by *E. coli* was greatly influenced by the temperature at which the cultures were incubated after irradiation (*A. Hollaender*). Maximum recovery was obtained when cultures were kept at suboptimal temperatures, such that cell division is reduced but enzyme activity not greatly affected.

The term "dose reduction factor" (DRF) is used to describe the ratio of doses required to produce the same radiation effect when different conditions prevail before, during or after irradiation. *Stapleton* and *Hollaender* have found that irradiation of *E. coli* at very low temperatures (77° K) causes less damage than at temperatures around 275° K or above. If low temperature is combined with $Na_2S_2O_4$, which is a good chemical protector, a maximum DRF of 14 is obtained (compared with room temperatures in the presence of O_2). This is equivalent to a reduction of the damage to bacteria to 2–5% of that which would result from the same dose under different conditions. Hollaender suggests that protection is complete for the indirect action of radiation, the remaining 2–5% of damage being due to direct hits.

RADIATION EFFECTS ON DNA SYNTHESIS

Å. Forssberg and *G. Klein* (Stockholm) have irradiated mouse Ehrlich ascites tumor cells *in vivo* with 1,250 r of X-rays, causing a drop in the mitotic index at 2 hr with later recovery, but no increase for 48 hours in the number of dead cells nor change in the rate of increase of N and RNA per cell, compared with unirradiated cells. The observed cell volume increase was thus due to cell growth in the absence of division and not to imbibition of water. The DNA per cell, however, did not increase during this period. With injected C^{14}-labelled glycine, it was shown that the specific activity of DNA increases in a manner similar to controls during 80 min following irra-

diation, after which time there is no further increase up to about 28 hr.

The presence of activity in extracted DNA is taken to indicate synthesis of new molecules, in addition to some turnover and exchange reactions not due to synthesis proper. This conclusion is drawn from the fact that when young and old tumor cells are compared, the ratio of their growth rates is similar to the ratios of the specific activities of RNA and protein; but the ratio of the specific activity of DNA is nearly twice as high in the rapidly growing young tumors.

In regenerating rat liver *B. Holmes* (Cambridge) has found that DNA increases from about 12 to 24 hr after partial hepatectomy, while mitosis first appears at about 21 hours. If 300 r of X-rays are given at 12, 18 or 24 hr after partial hepatectomy, both DNA synthesis and mitosis are delayed. *Kelly* has used mouse liver regenerating after CCl_4 injection, and has observed that DNA synthesis precedes mitosis. Further, if 800 r are given at an early time, when DNA synthesis is high but before mitosis starts, the values for DNA synthesis are as high as in controls, for some hours, but drop below controls later.

The autoradiograph method, which has been used by *S. R. Pelc* and *A. Howard* (London) on bean root meristems, has shown that in this material DNA synthesis (as judged by P^{32} uptake into DNA not removed by *N* HCl at 60° C) occurs about the middle of interphase in cells preparing for division. Irradiation prevents those cells in the first part of interphase at the time of irradiation from synthesizing DNA, but cells already in synthesis are unaffected in this respect. Cells in other stages of the mitotic cycle are able to synthesize in their next interphase unless chromosome damage renders them inviable. The processes that enable a cell to synthesize DNA later are very radiosensitive, and the full effect in this respect on cells at a sensitive stage is gained with 50 r, whereas cells at other stages of the mitotic cycle are unaffected with regard to this lesion by 200 r (MLD for the organ is about 180 r).

In attempting to relate these findings to the results of biochemical analysis, it seems possible that in the ascites tumor (Forssberg and Klein) and the mouse regenerating liver (Kelly) the absence of the effect on DNA synthesis at early times after irradiation may be due to a relative resistance on the part of those cells already in synthesis when irradiated. Further, it seems possible that in some tissues, notably the Jensen rat sarcoma studied by Hevesy and by Holmes, the fact that the rate of synthesis does not fall below about 50% of controls at short intervals after irradiation may be due to high sensitivity of only part of the mitotic cycle.

In considering the possible reasons why DNA synthesis should be such a radiosensitive process, we must attempt to visualize the mechanism of this synthesis. *Butler* pointed out that since the DNA molecule is maintained rather rigidly by H bonds between the bases, any chemical change in a base will affect the configuration of the molecule. Such a change in configuration is shown by the decreased viscosity of DNA irradiated *in vitro*, and Butler pointed out that this decrease occurs after much smaller doses than those necessary to produce any detectable chemical change. Hollaender (quoting *N. Anderson*, Oak Ridge) stated that in very highly viscous DNA a dose as low as 50 r can be recognized by about 20% lowering of viscosity.

If a scheme is accepted such as that proposed by Watson and Crick (*17*) for the configuration and reproduction of the DNA molecule, it would follow that the breakage even of one H bond in a chain would stop synthesis by preventing the new chain from fitting the old. *S. Pelc* pointed to the difficulty that the amount of DNA present in a cell nucleus (in contrast to the high dilutions in the *in vitro* experiments) is very large relative to the number of ion pairs produced in this volume by a dose of 50 r. Thus it is not possible that more than one in a thousand or so molecules could be initially affected by the formation of an ion pair as a monotopic effect. A means of avoiding this lies in supposing some organelle in the cell, which controls DNA synthesis and which presents a large target area. It has been suggested by Holmes (*18*) that it is not the phosphorylation of DNA that is interrupted by irradiation, but the build-up of the bases. It might be supposed that these, or some other essential constituent of DNA, might be produced under the control of an enzyme system that is especially sensitive, at a certain time in the cell cycle, to a radiation-produced radical.

CARCINOGENIC EFFECTS OF IRRADIATION

A. Glücksmann (Cambridge) has concluded from his studies of mouse skin irradiated with 1-Mev electrons (which penetrate to about 1 mm) that the production of cancer by irradiation is a slow discontinuous process and cannot be ascribed to the immediate production of mutations in irradiated cells. Malignancy appears infrequently and after a long period (14 months in one experiment), during which unstable secondary scars, which break down and regenerate in cycles, are formed mainly from subcutaneous connective tissue. It arises from immigrating nonirradiated cells. After benzpyrene painting a very different picture is seen; cancer appears after a much shorter period (70 days) and in a higher proportion of treated animals, and arises from hyperplastic tissue produced by the treated cells.

In contrast to Glücksmann's tumor rate of 15% of surviving mice treated with 8,900 rep of electrons, *B. V. A. Low-Beer* (California) has not observed tumors in human skin treated with 23,000 rep of β-radiation from P^{32} and Sr^{89}, which has approximately the same penetration. The difference in results may be due to the greater thickness of human skin and to the dose rate, as pointed out by Glücksmann, or to the different depth dose distribution, as pointed out by *P. Howard-Flanders* (London).

With regard to the appearance of tumors in other sites after irradiation, Glücksmann stated that his treated mice had not shown more than the expected spontaneous rate. There may, however, be an increase in frequency, or shortening of the latent period, in rats. *Cronkite* reported that in Sprague-Dawley rats, where the spontaneous tumor incidence is extremely low, animals irradiated with a LD-100 dose while protected by parabiosis, and later separated, afterwards showed a number of carcinomata of various kinds. On the other hand, he has not seen many tumors in animals that had received high doses with chemical protection.

SOURCES OF VARIATION IN RADIATION RESPONSE

The number of breaks induced by X-rays in Drosophila chromosomes (*K.*

G. Lüning, Stockholm, in collaboration with *G. Bonnier*) as measured by dominant lethals, is influenced by the stage of spermatogenesis at which they are irradiated and by the age of the male at the time of irradiation. Further, more breaks are induced in sperm irradiated in the female than in the male.

These changes are not paralleled by changes in the rate of gene mutation, and Lüning concludes that apparent gene mutations are due to both inter- and intragenic changes, the latter being apparently independent of the rate of chromosome breakage.

Glücksmann, quoting *I. Laznitsky* (Cambridge), reported that the mouse ascites tumor S37 is more than twice as radiosensitive when irradiated *in vitro* in its round-cell (ascites) form than in a spindle-cell form, as judged by number of takes after reimplantation.

P. C. Koller (London) discussed a number of biological factors known to influence the effects of radiation on cells and tissues, and the complexities and difficulties that attend the interpretation of cytological results.

CONCLUSION

Knowledge of the absorption of energy from ionizing radiation in gases and crystals is based on a large body of experimental evidence, but the understanding of transformation and degradation of the primarily absorbed energy in liquids is made difficult by lack of experimental data. Our ideas of the spatial distribution of ions and radicals in irradiated liquid systems may well undergo revision as a result of further theoretical considerations. Such a revision would alter the interpretation of radiation chemical effects, and improvement of understanding in this direction would help to clarify the nature of the initial lesions produced in biological materials.

Some common mechanism or causal connection between chemical or biological damage is indicated, however, by the appearance of certain similarities when recent radiation chemical work and some biological effects of radiation are considered together. One of these is the effect of oxygen. Oxygen generally increases X-radiation effects but is ineffective with high-ion-density radiation, both in chemical and biological systems. A biological exception, the inactivation of bacteriophage, is paralleled by certain radiation chemical systems and may be explained on radiation chemical grounds. A second important observation now emerging is that chemical protectors are ineffective in biological as in chemical systems against high-ion-density radiation, a result to be expected from current radiation chemical theories.

In considering radiation protective chemicals, it is not easy to see any features they have in common, either of a chemical, biochemical or physiological nature. It appears to be true, however, that all chemical protectors are most effective biologically if given in amounts near their toxicity level.

The mechanism of action of those agents that promote recovery from radiation is unknown, and its clarification will emerge only in conjunction with increased knowledge of the nature of the lesion. In mammals, the development of the primary lesion into the damage eventually observed brings up questions of physiology, growth and differentiation that require much more biological knowledge for their interpretation than is now available.

The interpretation of RBE values is complicated by the fact that there are qualitative as well as quantitative differences in response to neutrons and X-rays. This suggests that there may be differences, in part perhaps due to O_2 tension, between different organs in their response to radiations of different ion densities; this point would be worthy of investigation.

DNA is a substance whose synthesis *in vivo* and whose depolymerization *in vitro* are both affected by doses of radiation that are low even in the biologically effective range. Interference with its synthesis by radiation can be regarded as one of those measurable radiation effects more closely related to the initial lesion than such end effects as death of the organism. For this reason, study of this and other metabolic processes in cells promises to be the field in which our knowledge of the events connecting primary lesion with observed damage to the organism may be increased on the biological side.

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The Future of Heavy Water Reactors

(*Continued from page 14*)

The second conclusion is that modest heat extraction rates should be abandoned. All projects that aim to extract less than 5 megawatts per ton are becoming obsolete. In Europe, we shall have to learn more about heat extraction, and metallurgy, and flow of coolants, and to aim high, instead of rushing to build something noticeably lower on the scale.

Deuterium has a property that probably will become important in some remote future, and that is its low binding energy. The deuteron is the second most fragile nucleus in nature. If a 2-Mev gamma ray strikes a deuteron, a neutron is freed that will release up to 10 Mev if it is absorbed in a suitable material. Someone might say that this potential source of energy will remain forever beyond our grasp. But then Rutherford said as late as 1936 that there would be no practical use of atomic energy within 100 years.

Whatever happens, heavy water can continue to be produced without fear that it will soon become obsolete as a means for obtaining power.

* * *

This article is a condensation of a speech given on August 11, 1953, at the Heavy Water Reactor Conference at Oslo, Norway.

Absolute Beta Measurement of Tritium Monolayers

Negligible self-absorption and reproducibility suggest H^3-labeled monolayers as reference sources for tritium-tagged specimens. Ilford G.5 and Kodak NTB 3, of emulsions tested, have highest sensitivity for H^3 betas (3×10^8–10^{10} electrons/cm^2)

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ATTEMPTS HAVE BEEN MADE to evaluate radioautographs in a quantitative way as a simple means of localization of radioisotopes in biological specimens (*1–6*). The application of tagged monolayers as secondary standards was developed for quantitative carbon-14 radioautography (*5, 6*).

Experimental Procedure

Preparation of the monolayers and their deposition on a hypophase followed the procedure introduced by Langmuir and Blodgett (*7, 8*) and applied by Beischer (*5, 6, 9, 10*).

The solution on which the tritium-tagged stearic acid* was spread contained 10^{-4} *M* barium chloride and 2×10^{-4} *M* $KHCO_3$ in double-distilled water. Oleic acid was applied as a piston oil. The metal, quartz, and Lucite plates on which the monolayers were deposited were well polished to avoid radiation losses by scattering.

Deposition on plates. The plates were covered by a single monolayer of stearic acid-stearate by dipping into the solution before spreading the stearic acid on the surface of the bath. They were then pulled out of the bath, a few minutes after spreading the radioactive monolayer. Step-form films were deposited on all materials by dipping the plates, covered by a monolayer, several times to decreasing depths. Each dipping adds a film, composed of two radioactive monolayers, which rests on the previously deposited layer but covers only part of its area.

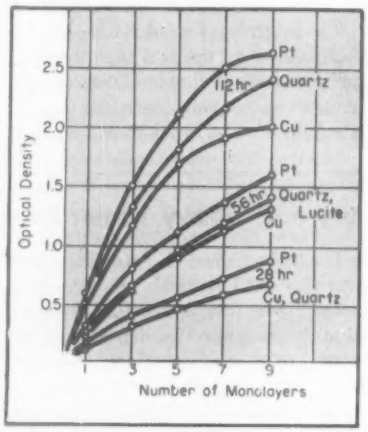

FIG. 1. Density-activity relationship for Ilford G.5 for different periods of time with H^3-tagged monolayers on various supporting materials

The film-covered plates were brought in contact with the photographic material soon after preparation. A printing frame was used to press the photographic plate on the monolayer. Usually, both sides of the supporting material were covered with radioactive monolayers and a photographic plate was pressed against each side. The exposure took place for different periods of time at 5° C. The medical X-ray film was developed in Rapid X-ray Developer and the nuclear plates (Ilford G.5 and Kodak NTB3) in D-19 for 4 min.

The density of the photographic emulsions was measured by an L496 Spectrogram Microdensitometer (Gaertner Scientific Corp., Chicago, Ill.) with a density range of 0 to 4.0. The density of the background fog was subtracted.

Results

Figure 1 demonstrates the influence of the activity of the source, expressed in the number of monolayers of tagged stearic acid, on the density of the Ilford G.5 plate. The effects of the exposure time and of the kind of supporting material are apparent.

Monolayer activity. The activity/cm^2 of a monolayer source is determined by the specific activity and the

* Tritium-tagged stearic acid was procured from Tracerlab, Boston, Massachusetts, on allocation from the Isotopes Division, U. S. Atomic Energy Commission, Oak Ridge, Tennessee. According to information from Tracerlab, the acid was prepared by catalytic hydrogenation of oleic acid. There should be not more than one atom of tritium on these molecules, which contain the isotope in the 9-10 position. The specific activity was given as 0.6 ± 10% mc/mg. This activity was determined by combustion to water, reduction to hydrogen, and counting by means of a calibrated Lindeman-Ryerson electrometer.

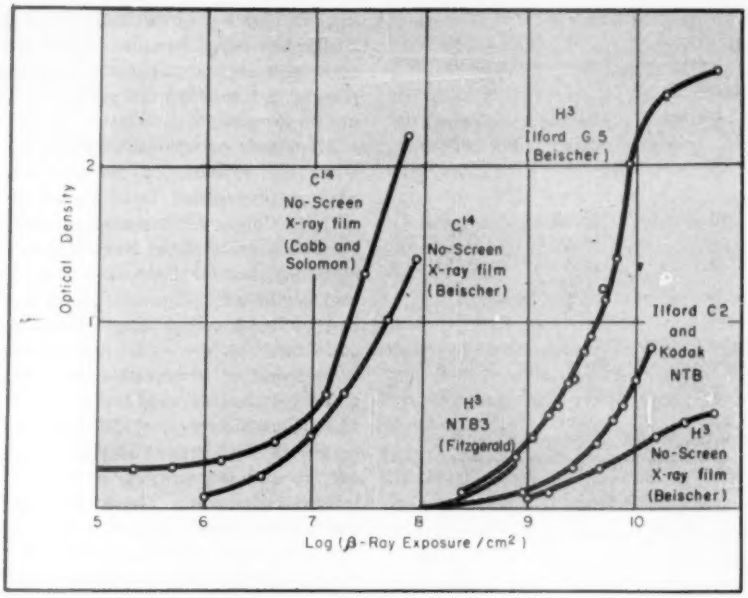

FIG. 2. Curves for several emulsions irradiated by C^{14} and H^3

weight of the substance in 1 cm² of the monolayer. The specific activity of the tritium-labeled stearic acid used in this study was $0.6 \pm 10\%$ mc/mg. The weight of a 1-cm² monolayer of stearic acid can be determined from the number of molecules per cm². This number is a constant for a given liquid substratum and a certain pressure of the piston oil (*11, 12*). Under the conditions used in the experimental procedure of this study, the value of 4.9×10^{14} molecules stearic acid per cm² was adopted. The weight of 1 cm² stearic acid monolayer is herewith 2.31×10^{-7} gm. Hence, the activity of 1 cm² of the tritium-labeled acid is 1.39×10^{-4} mc corresponding to 5.14×10^{2} dpm/cm², or 2.57×10^{3} beta rays emitted per second to each side of the monolayer. This value can be used to determine the number of beta rays emitted in different time intervals by films of several monolayers.

Backscattering. Information about backscattering is necessary to determine the number of electrons that cause the blackening of the photographic plate.

Part of the electrons emitted by the radioactive film in the direction of the supporting plate are scattered back through the source to the photographic emulsion. Conversely, electrons originally emitted in the direction of the photographic plate are scattered back to the supporting material before they are able to ionize the silver halide of the photographic emulsion.

If the saturation-backscattering values used are 80% for platinum (*13*), 23% for No-Screen Medical X-ray film, and 30% for nuclear emulsions (*5, 6*), the number of electrons that blacken the photographic emulsion can be determined. The number of electrons originally directed to the nuclear emulsion (2.57×10^{3} electrons/cm²/sec) is diminished by backscattering in the emulsion to 1.81×10^{3}. It is increased by the number of electrons that are backscattered from the platinum (2.06×10^{2} electrons). The number of electrons that finally blacken the emulsion is 3.87×10^{3} for platinum as supporting material.

This calculation does not consider the second-rate effects of multiple scattering between the two sides of the monolayer.

Characteristic curve. The characteristic curve for the Ilford plate (Fig. 2) is based on the monolayer on platinum (3.87×10^{3}) and data from Fig. 1. Similar curves for a number of photoplates under the influence of beta rays from tritium are plotted in Fig. 2. For comparison, the characteristic curve for the photomaterial that proved best for the detection of beta rays from carbon-14 (No-Screen X-ray film) is included.

The values of the table were obtained from Fig. 2. The sensitivity in this table is expressed in the logarithm of the total number of beta rays per cm² of film surface required to produce a density of 0.6 above background of the photographic emulsion. Lower numbers characterize a more sensitive, or faster, film. The contrast slope of the characteristic curve is given at a density of 0.6 above background fog. The values for the granularity were taken from values given by Rotblat (*14*). Carbon-14 data obtained with different films (*15*) are added for comparison.

This information was used to determine the activity of tritium-tagged compounds adsorbed from solution on different surfaces. The unknown samples were exposed for the same time and to the same photographic plate as the standard. This procedure excludes possible errors by the developing procedure. With the same backscattering material for sample and standard, the densities in different areas of the sample can be directly compared with the standard wedge and expressed in mc/cm². Results of this study will be reported later.

Difficulties were encountered in the measurement of samples with tritium distributed in the volume of the sample. The radioautographic method gives only the number of electrons that reach the photographic emulsion. Information about the self-absorption and the backscattering of the specimen is necessary to transform these data to activity in mc/cm³. In a first approach, the assumption can be made that the electrons measured at the surface of an organic specimen originate in a layer of 1μ depth. This assumption gives an approximation of the volume activity of the specimen.

Discussion

The usual preparation of standard sources by evaporation of a measured amount of solution of an isotope encounters difficulties in working with tritium. Due to considerable self-absorption, the activity of the source depends very much on the grain size of the precipitate. The selfabsorption of a tritium-tagged multilayer film is insignificant, at least as long as its thickness is less than ten monolayers. In this range, the tritium-tagged films can be considered as "weightless" sources of "zero thickness," a quite unusual

Characteristic Data of Exposed Films

Film	*Sensitivity* $\left(\log_{10}\frac{\beta\text{-rays}}{cm^2}\right)$	*Contrast (slope)*	*Granularity (microns)*
Ratings for Exposure to Tritium Radiation			
Kodak No-Screen Medical X-ray Film*	10.7	0.15	9
Kodak Nuclear Track Plate NTB	9.8	1.5	0.2–0.3
Kodak Nuclear Track Plate NTB 3	9.3	1.5	0.2–0.3
Ilford Nuclear Plate C.2	9.8	1.5	0.16
Ilford Nuclear Plate G.5	9.2	1.5	0.18
Ratings for Exposure to Carbon-14 Radiation (15)			
Eastman No-Screen X-ray Film	7.2	2.3	9
Eastman Nuclear Track Plate NTB	9.2	2.0	1

* Background fog 0.2. The background fog of the Nuclear Plates was about 0.05.

phenomenon for an isotope with such a weak beta radiation. Also, deposited films bridge any small unevenness of the surface, improving the contact with the photographic emulsion.

Monolayers prepared under the same conditions always deposit the same number of active molecules on a unit area of surface. Such reference sources can be used for absolute measurements, since the number of beta rays emitted from the active layer and the number of electrons striking the photographic emulsion can be calculated. A condition for this calculation is the simple geometrical arrangement of the emitting layer between the supporting material and the photoplate. This geometrical arrangement is very similar to the procedure used in radioautography of unknown samples. In the latter samples, the activity is usually distributed all over the thickness of the sample. However, only electrons originating nearest to the surface can reach the photoplate. The spectrum of the energy distribution of these electrons may be somewhat different from the spectrum of the monolayer standards. This difference will only be a second-order effect. A standard with the active atoms homogeneously distributed in the volume of the solid phase would eliminate this possible error. But such standards with different activities are not readily available.

A valuable contribution of the monolayer sources to radioautography is the possibility of depositing layers with the same activity on the surfaces of different materials. In this way, the amount of saturation backscattering can be easily measured and compared. With the backscattering of platinum (80%) as a reference, a value of 60% for copper can be determined from the data in Fig. 1. These backscattering coefficients were determined under the same geometrical conditions that are present in the radioautography of unknown samples.

Monolayer sources with multiples of a certain activity, in contact with photographic plates for different periods of time, offer a means to check the applicability of the Bunsen-Roscoe reciprocity law for the weak beta radiation of tritium. Figure 1 shows that this law holds over a range of activity and time.

Behavior of photoemulsions. The monolayer method readily makes possible the comparison of different film emulsions with regard to their qualities in radioautography of tritium-labeled specimens. The stable light source combined with an absorbing wedge, which is usual in spectral photometry, is replaced by a source radiating multiples of a basic activity (activity wedge).

Figure 2 and the table disclose a unique influence of the radiation of tritium on the photographic material. The No-Screen X-ray film, which is best for the detection of beta rays from carbon-14, shows a low sensitivity with tritium. The Ilford G.5 has the highest sensitivity and the best contrast, closely followed by the Kodak NTB 3. The recommendation to handle the latter in complete darkness is, however, a disadvantage in radioautographic work. The Ilford C.2 and the Kodak NTB are less sensitive. The No-Screen X-ray film needs about 10 times more electrons from the tritium source to reach the same density as the above-mentioned emulsions, and the contrast is low.

Drawing conclusions from data published for other elements (*16*), a much higher sensitivity of all the photoemulsions for tritium radiation should be expected. Figure 3 shows that the sensitivity of the photographic emulsions depends not only on the number, but also on the energy of the electrons. In this figure, a tendency to a greater sensitivity of the photo-material for less energetic electrons is noticeable. This tendency reaches a maximum for carbon-14, where a No-Screen X-ray film is blackened to a density of 0.5 by 1×10^7 electrons, a number even smaller than expected from a prolongation of a line through the values of other elements. In this respect, the low sensitivities for radiation from

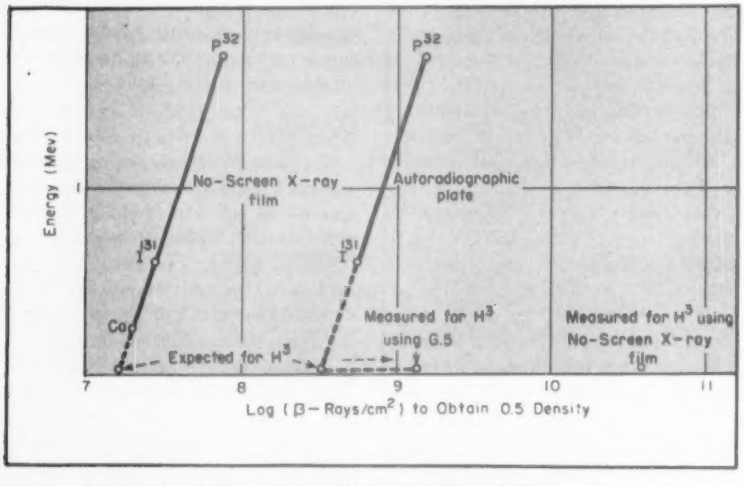

FIG. 3. Comparison of H^3 sensitivity with those of I^{131} and P^{32}

tritium, most noticeable with the No-Screen X-ray film, is quite unexpected.

The electron microscopic pictures in Fig. 4 represent sections cut perpendicular to the surface from the Ilford G.5. The emulsion was exposed, developed, and then embedded in polymerized *n*-butyl methacrylate. The pictures demonstrate that only the topmost layer, of about 1μ thickness, is influenced by the beta radiation from tritium. In pictures with low tritium-radiation exposure, the major part of the blackening is concentrated in a fraction of a micron below the surface.

This effect on the photographic plate is easily explained by a look at the beta spectrum of tritium, which shows that a great fraction of the radiation has an energy under 3,000 ev. At this small energy, the effect of the beta radiation very much depends on the composition of the plate. In the emulsion of the No-Screen X-ray film, with a grain size of about 9μ, a large number of electrons never reach a grain and spend their ionizing power in the supercoat and embedding gelatin. Even at the high silver halide concentration of about 80% and the small grain size of about 0.2μ, which are characteristic for nuclear plates, a number of electrons spend their total energy in the gelatin of the emulsion. This leads to a sensitivity for radiation from tritium that is lower than expected, judging from experiments with other elements.

At present, the nuclear plates are, however, the best approach to a desirable, highly sensitive, and rapid emulsion for radioautography of tritium-tagged specimens. They also have the advantage of low background fog.

With a clear understanding of the special problems of radioautography of tritium, a development of special emulsions for this purpose would be rewarding. Such a development might take as a stimulus the hope that tritium radioautographs, properly made, will show a superior resolving power, which may exceed the values reached with radiation from other elements. Experiments in this direction are in progress in this laboratory.

Limits of measurable activities. The lowest activity that can be measured by radioautography was not determined experimentally in this study. However, some conclusions can be drawn from the available data.

A density of 0.1 above background in an area of 1 mm^2 can be measured with Ilford G.5. This corresponds to 3×10^6 electrons. If this number of electrons is accumulated in 20 days, the source has to emit only 2 electrons/sec/mm^2, which corresponds to an electrical current of only 3×10^{-19} amperes. This sensitivity of the radioautographic method would surpass the sensitivity of the ionization-chamber method.

The greatest surface activity that may be registered under ideal conditions can be determined from the number of silver halide grains in a layer of 1μ thickness and 1-cm^2 area. This number is 10^{10}. Under the assumption of a grain yield of unity, 10^{10} electrons/cm^2 should be a limiting value for Ilford G.5. This value corresponds well with a saturation value of 10^{10} to 10^{11} electrons measured for this plate (Fig. 2).

Charged backscatterers. In the course of this study, another observation was made that is characteristic for radioautography using tritium. The high backscattering of isolating materials like quartz and Lucite (Fig. 1) need a special explanation.

The fact that the backscattering of these materials increases with increasing exposure time makes an electrical charging of the supporting material a convincing explanation of this phenomenon. After 28-hr exposure, a quartz supporting plate, which has only about one-third the density of copper, scatters as much radiation to the photographic plate as the metal. Lucite, with a density one-seventh that of copper, has, in experiments of 56-hr exposure, a greater backscattering coefficient than the metal plate.

With still longer exposure, backscattering approaches the values for platinum. In these cases, the stream of electrons coming from the tritium-tagged film is absorbed in the topmost layers of the isolating supporting materials. This forms a charged layer that repulses later-coming electrons electrostatically like an electron mirror and bends their course to the side of the photographic plate. The emulsion, in the case of the "charged backscatterer," is exposed to a greater stream of electrons than would be expected from backscattering values based only on the density of the material. This phenomenon was not observed in radioautography with other elements because the charge, due to the wide range of the electrons, is not concentrated in a surface layer as in the case of tritium radiation. It may be necessary to keep this charging effect in mind in evaluating radioautographs of dried tissue specimen tagged with tritium. The electric conductivity will prevent the build-up of an appreciable surface charge on metals and the photographic emulsions.

* * *

Opinions and conclusions contained in this paper are those of the author; they are not to be construed as necessarily reflecting the views or the endorsement of the Navy Department. The paper on which this article is based was presented at the conference on the use of tritium in organic and biological chemistry, Argonne National Laboratory, Lemont, Illinois, 1953.

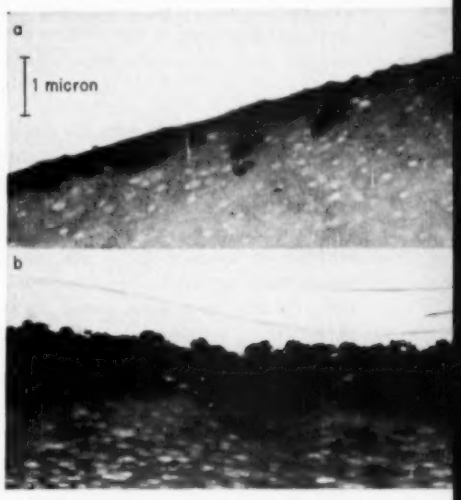

FIG. 4. Electron microscopic section of Ilford G.5 emulsion: (a) low exposure, (b) saturation exposure

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Experimental Techniques in

Gathered together in this two-part article is the basic information needed to conduct research with magnetic spectrometers. Considered here are techniques for source preparation, methods of gamma-ray measurement, and design problems of intermediate, evacuated regions of the spectrometer

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THEORIES ASSOCIATED with the design and operation of a magnetic beta-ray spectrometer have been presented in a thoroughly adequate manner by Persico and Geoffrion (*1*). But there are a number of existing facts and techniques that cannot be predicted theoretically but have been found in an experimental manner.

This article presents a compendium of these techniques. Consideration of the spectrometer is divided into four parts. Beta-ray sources and the intermediate regions within the spectrometer vacuum chamber will be discussed here; detectors and auxiliary equipment will be considered in the second part of this article.

Source Preparation

Source thickness and uniformity are the two major factors in source preparation. It is desirable to have a uniformly distributed source as thin as possible but of sufficient strength to be recorded in the spectrometer. An ideal source, with considerable strength but zero thickness, is impossible. If a source is of finite thickness, those electrons whose paths begin near the back of the source must travel through it before emerging into the spectrometer. Thus they will be degraded in energy by ionization and excitation of the atoms in the source. Because of scattering, their actual paths may be longer than the measured thickness of the source material.

Two of the most common methods of preparing thin, uniform sources are chemical deposition and thermal evaporation.

Chemical deposition. The most commonly used method for preparing a source is by chemical deposition of a solution of the source onto a backing with subsequent drying under a heat lamp. Such sources when weighed may seem to be adequately thin. However, autoradiographs have shown (*2*) variations in intensity of the radiations from different parts of the source of as much as 100 to 1. A typical autoradiograph is shown in Fig. 1. The thicker portions of the source cause distortions in the lower-energy portion of the beta spectrum, as was observed (*3*) in the case of Cu^{64}. See Fig. 2a. Of course, if the source material is carrier free and the amount of solids in the solution small (*4*) these variations in local thickness will not effectively distort the results.

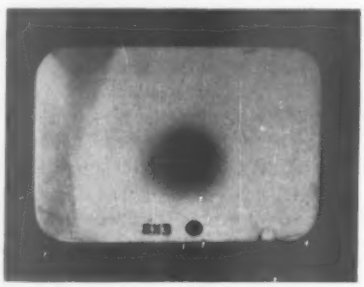

FIG. 1. Autoradiograph of chemically deposited source shows nonuniform distribution of material

If there is no other way to prepare a source except by chemical deposition, very rapid drying of the deposited solution by an infrared lamp together with slight agitation of the liquid prevents the formation of large crystals and produces a relatively uniform source (*5*, *6*).

Thermal evaporation. A thermal evaporation technique has been used (*2*, *7*) to prepare Cu^{64} sources. The chief difficulty encountered is that of limiting the deposition to the spectrometer source holder. Activity may easily be distributed to other parts of the evaporating system.

A modification of the method used for producing the Cu^{64} source limits the spread of the activity. This is done by an initial chemical deposition of source material on one side of a tungsten ribbon that is used as the filament for the evaporation process. The source holder is next brought into the region facing the tungsten ribbon. The source may then be deposited by evaporation with only slight loss of source material. Thin, uniform sources of P^{32} have been deposited by this means. See Fig. 2b. It has also been possible to separate different elements and get rid of superfluous solids by this technique (*8*).

Source Backing

Ideally no backing is desired for a beta-ray source. This condition has been approached only in the case of

* PRESENT ADDRESS: U. S. Naval Radiological Defense Laboratory, San Francisco, California.

Beta-Ray Spectroscopy—I

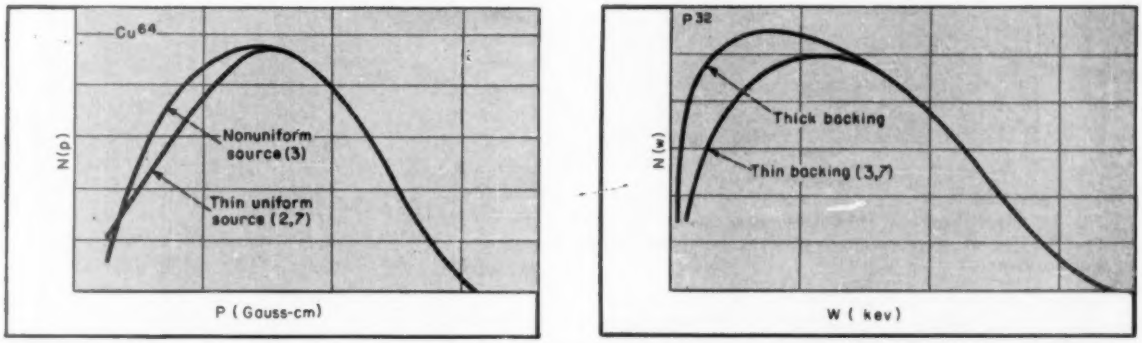

FIG. 2. Beta spectrum of Cu^{64} (a, left) illustrates effect of source thickness; spectrum of P^{32} (b, right) effect of backing thickness

the proportional counter in which the source is introduced as a part of the counter's gas (*9*). Even here a correction factor is sometimes necessary for events that occur near the counter wall. Unless extremely high pressures can be used within the counter (*10*), this technique is limited to the study of low-energy radiations.

In magnetic analyzers any material used for source mounting will produce backscattering of electrons and gamma rays. Experiments (*11*) show that for thin backings an initial increase in backing thickness produces a much larger increase in electron backscatter than do further increases. This is shown in Fig. 3. Electrons have a finite range in material and any increase in backing thickness beyond some critical point produces no additive effect. This critical thickness is about ⅓ the range of the electron (*11*). To obtain a correct spectral shape for low-energy electrons, therefore, will require greater care in selection or preparation of backing than for higher-energy electrons.

For a given energy electron, a material having high atomic number produces a greater amount of backscattering than does one whose atomic number is lower (*11, 12*). Foils such as Zapon (*13*), Nylon (*14*), Formvar (*15*) and LC600 (*16*) are ideally suited as backing materials.

In the same category as backing problems is the matter of material in the vicinity of the source. The first baffle of the spectrometer should not lie in the immediate vicinity of the source, for the high radiation flux can produce undue scattering into the normal beam path. Any possible electron paths from any portion of the source holder should also be traced to avoid scattering. All parts of the source holder should be built at sufficient distance from the source to prevent such scattering. Special care must be taken in the larger magnetic spectrometers since distances between source and holder are appropriately larger.

Source Charging

If the source is not properly grounded, charging may occur, thereby distorting and shifting the observed spectrum (*17, 18*). The source may be connected electrically to ground through an aluminum strip or a hair made conducting by application of a colloidal graphite dispersion. Evaporation of a thin layer of copper on the reverse side of a Zapon foil also has been used (*19*).

Charging in negatron emitting sources may be greatly reduced by supplying a low-density cloud of electrons immediately behind the source (*20*). This keeps the negatron emitting source near ground potential.

Dielectric effects can be overcome by using a metallic-foil backing material. Certain limitations enter into the use of such foils, chief among which is the desire for a material having low Z. Beryllium is not easy to handle. Carbon cannot be adequately formed into a thin foil. There is a strong chemical reaction between magnesium and a large number of solutions used to prepare sources. Aluminum, for many purposes, is the best of the metallic backings.

A limitation on the use of metallic conducting backings is that there is no certainty as to the lower energy limit for which a true spectrum can be obtained. The 0.00025-inch aluminum backing appears to give a true spectrum to 50 kev (*7*). This lower limit is not established for organic foils either, but experiments (*5*) on Pm^{147} indicate 5 or 6 kev.

Less Common Sources

Electroplated, gaseous, and powdered sources have also been used. Electroplating a source requires that the backing foil be electrically conducting and thick enough to be strong mechanically. Backscattering from the backing limits use of this method to higher-energy measurements. The source is limited to materials that can be electroplated.

Aluminum backing is not very satisfactory. Graphite 0.010 inch thick (*21*) and copper 0.0005-in. thick have been used successfully as backings for electroplated sources. Thin backings to which sources can be electroplated have also been prepared (*22*) by evaporating a thin layer of copper onto a Zapon backing.

A gaseous source is uniform (*23, 24*). However, the gas must be contained. A foil having sufficient strength to

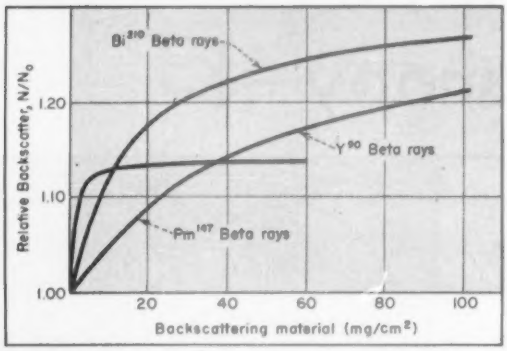

FIG. 3. Effect of backing on intensity measurement. Relative number of back-scattered particles increases with backscatterer

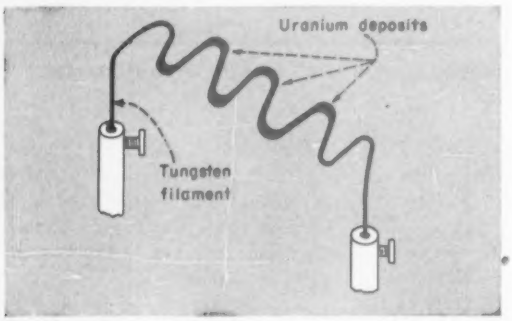

FIG. 5. Filament arrangement used for thermal evaporation of uranium to produce thin gamma-ray radiators (30)

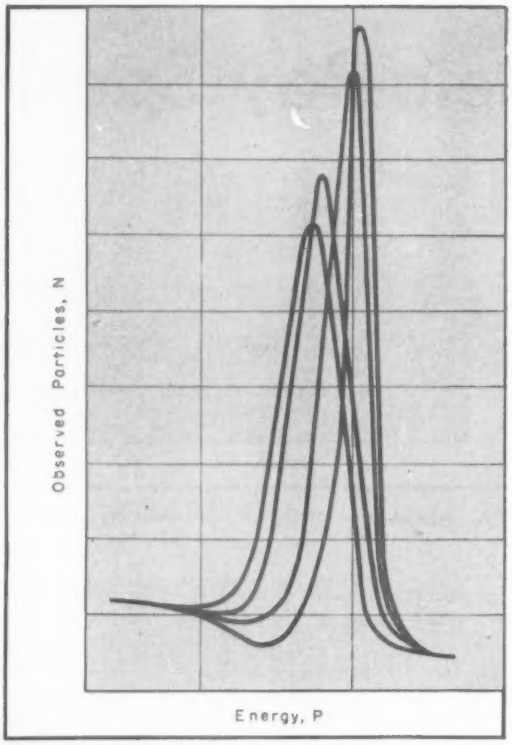

FIG. 4. Effect of source thickness on shape of internal-conversion lines. Narrow, taller peaks are produced by thinner sources (29)

withstand the pressure between a gaseous source and the vacuum within the spectrometer chamber will add artificial thickness to the source.

Sometimes the source material can be prepared in the form of a fine powder and an acceptable source prepared by scattering this powder onto the gummed side of a piece of Scotch tape. The powder must be extremely fine, for individual grains of powder having a coarse texture may produce the same distortion as a thick source (*25*).

Gamma-Ray Measurements

Gamma-ray energies and intensities are customarily measured in beta-ray spectroscopy by making measurements on the secondary electrons to which these gamma-rays give their energy when they interact with matter. Such events take place both as internal conversion, in which case the electron is ejected by the radioactive atom in lieu of a gamma ray, or by external conversion, in which case the gamma ray from a radioactive atom interacts with an electron belonging to another atom. Internal-conversion sources are prepared exactly like beta-ray sources.

For external conversion the spectrometer's electron source is not the radioactive material but a thin foil known as a radiator. The radiator is placed immediately in front of the radioactive material, and interactions take place between the gamma radiation and the atoms of the foil to produce Compton electrons, photoelectrons and pairs, in amounts dependent upon the gamma-ray energy and the atomic number of the radiator.

To prevent direct measurement of the electrons emitted by the radioactive substance, some material of low atomic number having a thickness just sufficient to prevent their escape must completely surround it (*26*).

It is customary to emphasize the photoelectron peaks in an external-conversion measurement of gamma-ray energies. The cross section for the photoelectric process increases as Z^5 (*27*). Radiators are therefore made of materials having high atomic number: usually lead, thorium or uranium. Foils having surface densities less than 50 mg/cm² have been found satisfactory. The thinner gamma-ray sources produce better resolution but lower intensity for both external conversion (*28*) and internal conversion (*29*). This effect is shown in Fig. 4.

Reasonably thin lead radiators may be rolled. But, with the exception of the National laboratories, few laboratories are prepared to handle and roll thin foils of uranium.

Thin foils of both lead and uranium have been thermally evaporated (*6, 30*) in vacuum. Vacuum evaporation of lead is simple since only low temperatures are required. However, the evaporated layer is extremely delicate and is easily rubbed off. Vacuum evaporation of uranium is more difficult because of the higher temperatures required. The uranium must be very pure to have a reasonably low melting point. Furthermore, if the uranium is in direct contact with the tungsten filament, a reaction causes the filament to disintegrate. There seems, however, to be no tendency for the tungsten to evaporate with the uranium (*30*).

Hedgran and Lind (*30*) use a 0.080-in.-diameter tungsten filament, shaped as illustrated in Fig. 5. The bends are filed flat and a small piece of uranium placed on each flattened region. The

thick filament requires a large current such that the leads need artificially applied cooling. A diffusion pump having a speed greater than 100 liters per second is required to maintain the necessary vacuum. In this way foils having thicknesses up to about 3 mg/cm² have been prepared. The thicker foils did not deposit uniformly; thus the method is suitable only for preparation of very thin uranium foils.

A number of methods for preparing uranium and other foils have been discussed by Dodson *et al.* (*31*).

Gamma rays may cause difficulties in the measurement of beta-ray intensities. An example has arisen in the study of the high-energy beta spectrum of Sc^{46}. The isotope Sc^{46} has two gamma-rays, 0.89 and 1.12 Mev. A study of the spectrum above the known end-point, 0.36 Mev, of the main group of beta rays reveals a continuous spectrum, at least part of which may be a distribution of Compton electrons produced in the source by the gamma radiation (*32*). A small portion of the intensity of the observed internal conversion lines thus actually may be the result of photoelectrons externally converted within the source.

If proper precautions are taken while studying internal-conversion lines, solid or very thick backings may be justified (*30, 33*). Electrons scattered into the spectrometer from the backing must be scattered through large angles. The probability for such scattering is very small. Thus most scattered electrons travel a considerable distance within the backing before returning to the spectrometer's electron beam and lose considerable kinetic energy. Because of the random nature of their paths, their distribution of energies may be considerable. The scattered electrons produce only a slight increase in spectral intensity and appear at such degraded energies that they do not affect internal-conversion line spectrum.

Intermediate Regions

In this region between source and detector, magnetic analysis of the momenta of the electrons is made. The vacuum must be sufficiently good to prevent scattering of the individual electrons by gas within the chamber. An appropriate baffle system must be constructed to define the path of the beam and prevent scattering into the spectrometer's detector of electrons that reach the walls of the system.

The one baffle that defines the beam is usually located near the midpoint between source and detector (*1*). For photographic spectrometers it is closer to the source. The number of baffles within a spectrometer, exclusive of the defining baffle, has varied considerably. Some designers feel that a large number of baffles are needed to define the beam and thus prevent scattering from the walls of the chamber. Others say that a single defining baffle should be adequate. Otherwise, they say, considerable scattering will take place at the edges of the baffles.

Experiments indicate that the best arrangement seems to be an intermediate point of view (*34*). A single baffle is inadequate; three baffles appear to be sufficient. There is no significant change in the measured results caused by a change in the atomic number of the material from which the chamber or baffles are made. However, less scattering takes place from materials of low atomic number.

Part II of this article . . .
. . . will include discussions of the use of beta-ray detectors (G-M and scintillation counters, electron multipliers), and of methods for producing, measuring, and controlling the required magnetic field.

The surface of the chamber and of the baffles must be electrically at ground potential. Otherwise a buildup of charge at some point in the spectrometer will distort results. If the system is made of plastic, a coating of colloidal graphite should be applied to all surfaces and grounded.

Since the path traversed by a beta particle in a spectrometer does not exceed one or two meters, reasonable care in following accepted vacuum practices (*35, 36*), should eliminate problems due to vacuum difficulties. Commercially available diffusion pumps can easily produce the required vacuum.

Most gaskets for the spectrometer vacuum system now are commercially available O-rings. Where it is desirable to have extremely low vapor pressure, a foil of some soft metal can be used. Many people (*36*) use indium or lead gaskets about 0.010 in. thick in any part of the system that will come in contact with the counter gas. This insures nonexistence of impurities from gasket material in the counter gas.

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Industrial requirements are related to possibilities for fission-product sources of gamma radiation in this study of future sterilization needs and how they can be met. Calculations indicate that megacurie sources will be required, but some uses such as insect control require lower doses than does sterilization

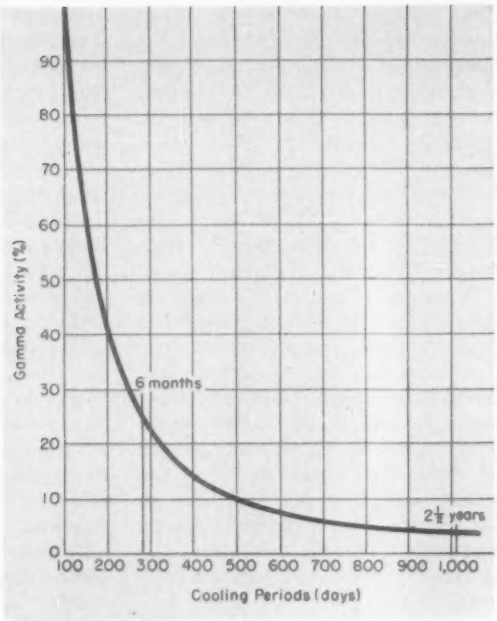

FIG. 1. Fission-product decay curve (datum: 100 days of cooling)

RADIATION STERILIZATION IV

Application of Isotopic Sources to Food and Drug Sterilization

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TECHNOLOGICAL DEVELOPMENT of fission-product sources has not advanced to the status where well-defined specifications can be set forth fully guaranteeing such devices as industrial sterilization machines. Much of the knowledge of the effects of gamma radiation on foods and drugs has come from research studies concerned with "pile exposed" sources (called "mock" fission-product sources) in the 1,000 to 10,000 curie range. Some consideration is being given to designs and future construction of an industrial prototype or a pilot fission-product source in the megacurie range.

In the absence of these future facilities, a limited engineering analysis of fission-product sources can be made, based on a knowledge of typical industrial production requirements and of the properties of waste streams from existing reactors.

Industrial Requirements

From the industrial point of view any consideration of the possible use of

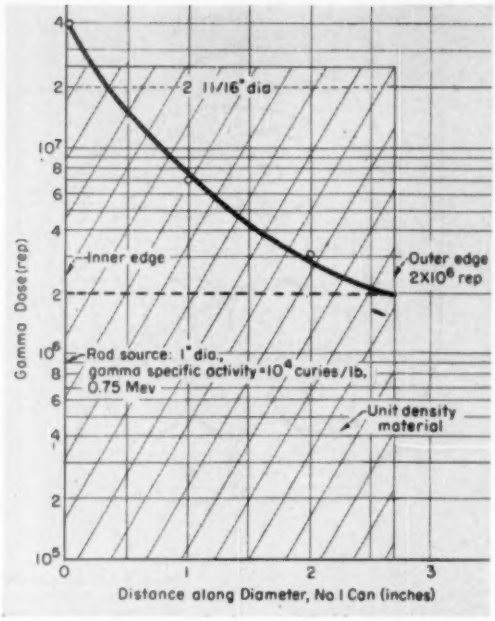

FIG. 2. Dose distribution in stationary No. 1 can irradiated with rod source to 2×10^6 rep at outer edge of can. Self-absorption of can neglected

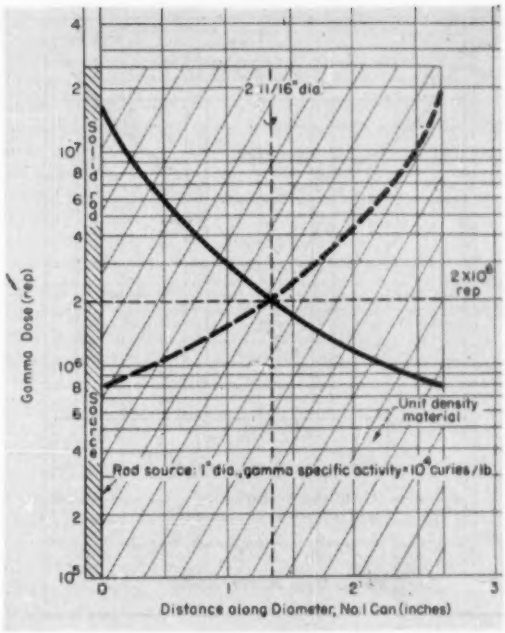

FIG. 3. Dose distribution in rotating No. 1 can irradiated with rod source to 2×10^6 rep at center of can. Self-absorption of can neglected

gamma-radiation sources for sterilization of foods and drugs would have to fulfill the following requirements:

1. Provide an improved product at an equal or lower cost competitive with the existing methods of sterilization or equivalent procedures.

2. Packaging and production line machinery and facilities represent a substantial capital investment—a radiation source must not radically alter these facilities.

3. Plant space for additional operations such as holdup or storage would be exceedingly expensive or unavailable; hence additional space requirements must be held to a minimum.

Fission-Product Resources

Present sources of fission products that are potential sources of radiation are associated with:

1. Process of separating an isotope or isotopes (e.g. Pu^{239}) from slugs.

2. Process of cooling nuclear power reactors.

3. Induced radioactive sources made by exposing metals such as Co^{59} in a reactor.

4. Small amounts of wastes from research laboratories working with radioactive materials.

5. Underground wastes now in storage.

6. Fuel elements from testing reactors.

Some authorities working in the fission-product program consider a future source of gamma radiation may be realized by use of solutions from power reactors (*1*, *2*). These solutions would contain high-specific-activity short-half-life fission products and might be circulated in special pipes. These pipes could be utilized as direct radiation sources.

Of the foregoing existing resources, the first appears to be the most important from the point of view of quantity and availability for industrial use. Fission products can be recovered from high-level active waste streams from an isotope separation plant by chemical processing operations such as evaporation, distillation, neutralization and calcination to reduce the bulk and increase the specific activity of the resultant source.

The end product of these operations will either be a slurry or dried active salts. The dried active salts can be jetted into tubular rod source shapes by an inert gas under pressure and then sealed.

An alternate method would be to cast the solids by dissolving the fission products in molten salts. The package container could be stainless steel or aluminum pipes about 1 in. in diameter.

Decay and Dosage

Fission products decay to a lower strength of activity depending on the cooling time. The specific activity of a source (curies per pound) changes rapidly over even a 6-month period. The rapidity with which fission-product activity falls off with time is illustrated in Fig. 1. It can be seen that at the end of a period of 6 months (datum: 100 days of cooling from reactor) only 25% of the initial gamma activity is still available; at the end of a 2½-year period only 3.5% of the activity remains. Thus, fission-product sources derived from high-level waste reactor streams may require a complete replacement as often as every 6 months.

A fission-product source has a continuous field of radiation that cannot be shut off with a push button. Thus, theoretically the best utilization of this field, say from a thin cylindrical rod source, is approximately attained by surrounding the source completely with the material to be sterilized to a radial distance of one mean-free-path for that material. For water at 1 Mev, this dimension is about 5.5 in. (the reciprocal of the linear absorption coefficient of water at 1 Mev). The

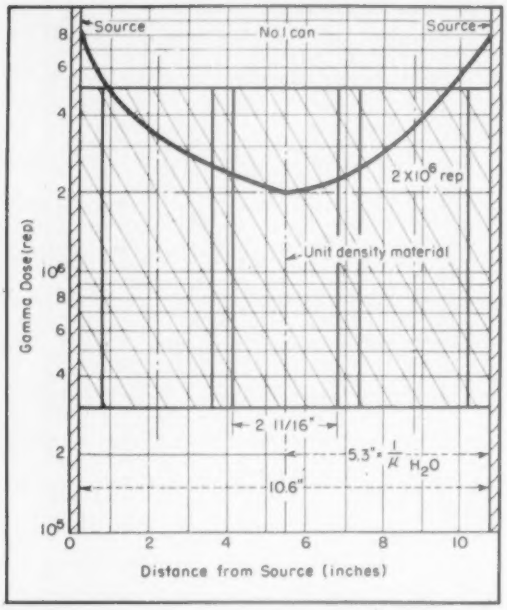

FIG. 4. Average dose distribution in layer of No. 1 cans irradiated within hollow source to 2×10^6 rep at center of can. Self-absorption neglected

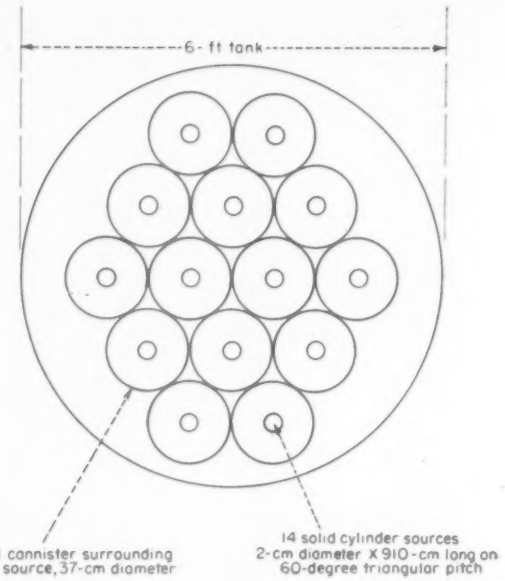
6-ft tank
Metal cannister surrounding each source, 37-cm diameter
14 solid cylinder sources 2-cm diameter X 910-cm long on 60-degree triangular pitch

FIG. 5. Cross section of solid cylinder source using 2.5×10^5 curies per rod to process 5,960 lb/hr of grain

material must remain exposed to radiation for a sufficient residence time to achieve a sterilizing dose (2×10^6 rep).

If a rod source is designed so that the dose rate is based on the outermost perimeter of the material being sterilized, then the material adjacent to the source receives a higher dose rate because of the exponential nature of gamma-ray absorption. This is illustrated in Fig. 2, which shows the dose distribution in a No. 1 can ($2^{11}/_{16}$ in. diameter by 4 in. long) of unit-density material exposed to a 1-in. diameter rod source. Figure 3 shows the effect of rotating a No. 1 can in a gamma radiation field from a rod source to give a more desirable dose distribution; peripheral overdose is reduced from 4×10^7 to 1.8×10^7 rep. Figure 4 illustrates the dose distribution through a layer of No. 1 cans within a hollow cylinder source with a radius of about one mean-free-path for water; overdose is reduced thereby to 8×10^6 rep.

It is evident that the problem of optimum dose distribution and dose-rate control must be solved in the conveyer designs or recirculating systems for industrial installations. Special conveyers such as screw, spiral or Redler types, in which the product would move as a solid core telescoping the source, are suggested as a partial solution to this problem.

Application

Sources for use with typical industrial products will have to be in the megacurie range. Table 1 indicates this in a qualitative way for three geometrical source shapes: hollow cylinder, thin plane and solid cylinder. The length of each source used in this table was arbitrarily fixed at 180 cm. Absorption is considered to be very nearly optimum for the target material (specific gravity = 1.00) at a thickness equal to the reciprocal of the linear coefficient of water, i.e. at one mean-free-path. For gamma radiation in the 0.75 to 1.00 Mev range, this dimension would be about 15 centimeters.

Data for two conditions of the target material are tabulated. Condition 1 represents the adaption to a minimal production flow rate where a substantial residence or holdup time of product from a feed conveyer system can be tolerated. Condition 2 represents direct adaption to conveyer systems at higher production rates. Condition 1 results in megacurie sources; condition 2 requires multimegacurie source strengths. Potential industrial installations will probably be a compromise between the cost of ultra-high level sources with minimal process alteration and the cost of process alteration, space and shielding to permit use of megacurie sources. The magnitude of the total dose required per pound sterilized

TABLE 1—Time Required for Static and Dynamic Irradiation

Source shape	*Condition*	*Material irradiated (gm/sec)*	*Total curies required*	*Total time to achieve dose of 2×10^6 rep (min)*
Hollow cylinder	1. Min. flow	70	1.52×10^6	30
Hollow cylinder	2. Prod. rates	2,120	46×10^6	1
Thin plane*	1. Min. flow	70	6.8×10^6	10
Thin plane*	2. Prod. rates	680	66×10^6	1
Solid cylinder	1. Min. flow	70	1.82×10^6	30
Solid cylinder	2. Prod. rates	2,120	55×10^6	1

* Only one side used.

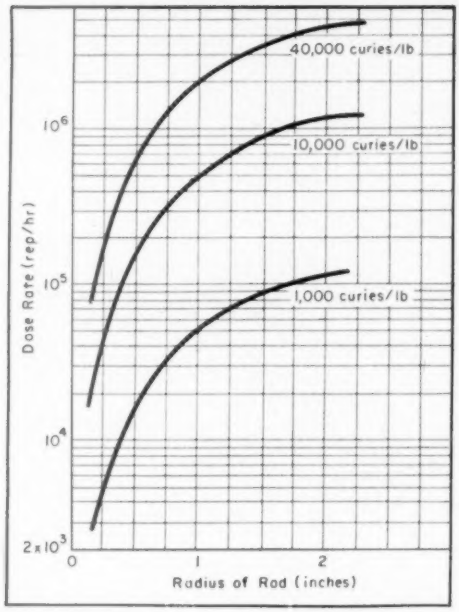

FIG. 6. Effect of rod thickness on dose rate for different specific activities

SYMBOLS

A = distance from edge of source to outer edge of material receiving radiation, cm (for hollow cylinder A = radius, R cm)
$B = \mu A + vZ$ for solid cylinder source (Fig. 10)
$B = \mu A$ for hollow cylinders (*3*, *6*)
C = Source strength, curies
C_A = Source strength per unit area, curies per cm²
C_V = Source strength per unit volume, curies per cm³
D = Dose rate in rep/sec
K = Conversion constant, line or solid cylinder source at 0.75 Mev = 39.7
K_1 = Conversion constant, hollow cylinder source at 0.75 Mev = $K/4\pi$
L = Length of source, cm
R = Radius of solid cylinder source, cm
V = Volume of source, cm³
Z = Self absorption dimension for solid cylinder, cm (Fig. 9)
$\bar{\beta}$ = Function $(L/A, \mu A)$ for hollow cylinder (*3*, *6*)
μ = Linear absorption coefficient of material receiving radiation, cm⁻¹
v = Linear absorption coefficient of source material, cm⁻¹
σ = Linear absorption coefficient of shield material, in.⁻¹
θ = Half angle (Fig. 8)
ϕ = Total angle = 2θ

will affect the size of the radiation source. The accepted value for most foods is about 2×10^6 rep; for deinfestation of grain this value is only 25,000 rep.

Equations for dose rate in terms of source strength activity for hollow cylinder, (*3*) thin finite plane (*4*) and solid cylinder (*5*) sources were used to estimate the curie requirements for typical industrial products; the calculations based on certain simplifying assumptions are contained in unclassified reports (*6*, *7*) to the U. S. Atomic Energy Commission.

The equations for the three source shapes are:

Hollow cylinder (inside)

$$D = 2\pi k_1 C_A \beta$$

Hollow cylinder (inside)(average)

$$\bar{D} = 4\pi k_1 C_A \bar{\beta}$$

Hollow cylinder (outside)(average)

$$D = \frac{KC_L}{4\pi A} f(\overline{\theta\beta})$$

Thin plane (average)

$$\bar{D} = 0.14 K C_A f(\bar{\theta}\beta)$$

Solid cylinder (average)

$$\bar{D} = \frac{KR^2 C_v}{2(A + Z)} f(\bar{\theta}\beta)$$

where symbols are those given on this page. The calculations involved in applying the equation for the solid-cylinder source geometry to insect control in grain are illustrated in an example at the end of the text.

The results of these calculations indicate that it will require about 3.5×10^6 curies to deinfest 83,500 lb./hr of grain at 25,000 rep. The utilization efficiency of the source is 14.7%. The installation consists of 14 cylindrical rod sources 2 cm in diameter and 910 cm (30 ft) long, arranged on a 60-degree triangular pitch (see Fig. 5) within a circular shielded enclosure.

The curie requirements for any installation as calculated by this method are the "terminal" curies of the source at the time when the source required renewal or replenishment. A larger number of curies would always be available at the time of installation.

The output of a fission-product source as a sterilization machine always falls off with time. This is illustrated for a typical rod type source in Table 2, which shows that at the time of installation the sterilization process rate is 500 lb/hr, but 60 days later the process rate is 104 lb/hr. It is, therefore, possible to rate the source on some median or average value. If the process rate is plotted against time, then by graphical integration the median rating of the source for the two month period is about 210 lb/hr.

If the source is rated at the median value, the user would be faced with a storage problem for the extra material sterilized when the rate exceeded the median. If, on the other hand, the rating is based on a terminal value, then the user would be charged for less gamma power than is available during the average period of use. These are considerations that will affect the initial cost of a radiation source.

Other factors affected by the decay curve are the specific activity (curies/lb) of the fission products, heat generation, and the shielding thickness. Figure 6 illustrates the dose rate in rep/hr as a function of rod source diam-

TABLE 2—Unit-Density Material Processed By Rod-Type Source*

Days after installation	*Gamma power (kw)*	*Process rate (lb/hr)*
0	6.3	500
10	4.2	335
20	2.9	233
30	2.1	168
40	1.7	136
60	1.3	104

* Median production by graphical integration = 210 lb/hr; assumed utilization efficiency = 17%.

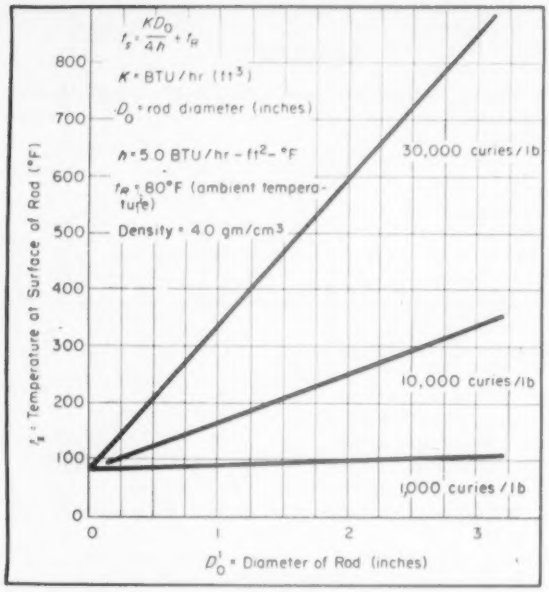

FIG. 7. Effect of rod diameter on surface temperature (developed from Brookhaven National Laboratory data)

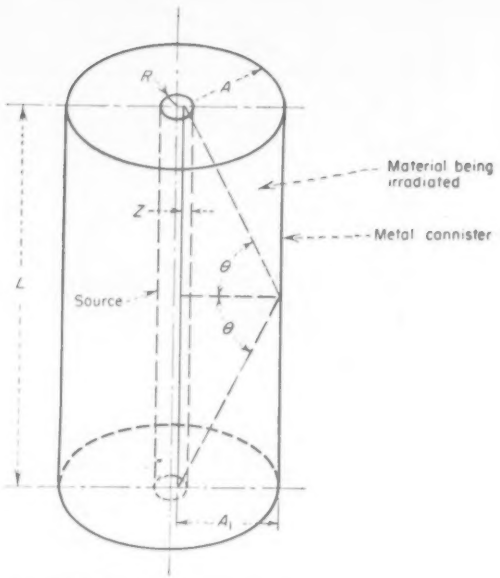

FIG. 8. Unit solid-cylinder source

eter with several specific activity parameters, for target thicknesses of about 1 mean-free-path for water at 0.75 Mev. It can be seen that at lower specific activities of the source it will take longer to achieve a total sterilizing dose because of the weaker radiation field. A larger installation would be required to make up for the weaker source intensity if a given production output rate is to be met.

At higher specific activities, consideration must be given to means of dissipating heat from the coexistent beta energy self-absorbed by the source. In mixed fission products there will be at least one beta curie coexisting with each gamma curie. Inasmuch as these beta curies will generate heat within the source, fission-product salts within a container such as metal rods must be completely free of water to prevent rupture due to pressure buildup.

The self-absorption effect dictates that sources must not be too thick. For rod sources, the maximum tolerable diameter will probably be around 1 in. For hollow cylinder sources, the wall thickness must be limited to the minimum compatable with structural rigidity.

Figure 7 indicates surface temperatures for various rod diameters based on a range of specific activity parameters. These curves were calculated from theoretical data developed by Brookhaven National Laboratory and are based on an ambient temperature of 80° F. At the lower specific activity of 1,000 gamma curies per pound, the surface temperature of the source is substantially constant over a wide range of source diameters; at the higher value of 30,000 curies per pound, the surface temperature rise is extreme, particularly above 1 in. diameter. This creates a design consideration in that heat-transfer equipment may be necessary to cool the surface of the sources by circulating air or water through a core in the rods until the fission products decay to a specific activity at which the material being sterilized will not be thermally affected.

The thickness of shielding required to protect personnel from radiation should be based on the higher source strength at the time of installation. When not in use, high-level sources could be telescoped into the ground for shielding. For portable lower-level sources, supplementary temporary shielding could be used when the source is installed. Table 3 indicates the shielding requirements for high-level sources at 1 Mev.

It is probable (from theoretical computations) (7) that utilization efficiencies will range from 15 to 25% for rod source installations and perhaps up to 35% for hollow cylinders if both inside and outside radiation fields are used. For plane sources, assuming both faces are used, lower efficiencies (around 10%) are estimated due to edge-effect losses.

Potential radioactive sources from unseparated fission products will be a compromise to the extent that the fission products will be of maximum specific activity compatable with a minimum of heat-transfer equipment and over-all bulk shielding of industrial installations. Maximum utilization of the radiation field for rod and hollow-cylinder sources must be achieved in the conveyer system designs.

Reliability, ease of installation and complete safety to producer and consumer are the minimum specification

TABLE 3—Shielding Requirements for Gamma Radiation (1 Mev)*

Radiation (curies)	*Lead (in.)*	*Concrete (in.) (sp. gr. = 2.9)*
10^4	7.5	33.9
10^5	9.0	40.6
10^6	10.4	48.8
10^7	11.9	53.5

* Courtesy of Stanford Research Institute.

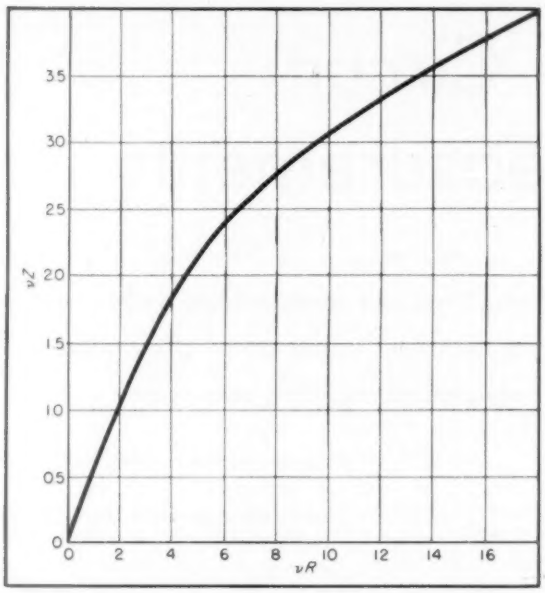

FIG. 9. Variables in dose-rate equation for solid-cylinder source

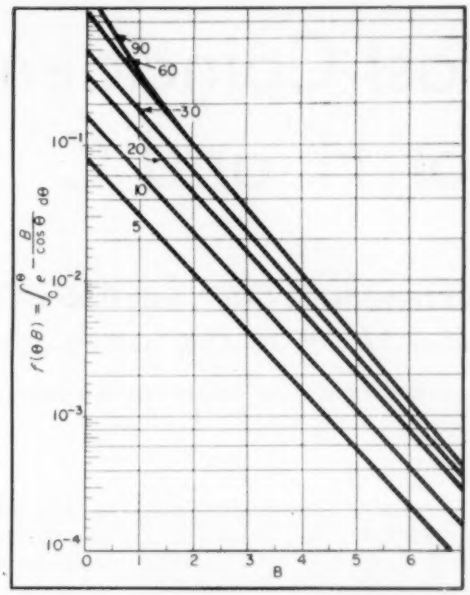

FIG. 10. Angular (θ) parameters for B in dose-rate equation for solid-cylinder and plane sources

requirements, in-so-far as sources of ionizing energy are concerned, which must be met before such devices can be accepted by industry.

Insect Control in Grain

In this example, a multiple-unit rod source is arranged similar to a vertical tube bundle. Each rod irradiates grain at 0.75 Mev and to a dose of 25,000 rep to a radial distance of 17.5 cm, about 1 mean-free-path in grain.

Assume that the unit rod sources contain mixed-fission-product salts of 22 curies/gm with a density of 4 gm/cm³; that the salts are contained in rods 2 cm in diameter and 910 cm long; that the linear absorption coefficient for fission-product salts $\nu = 0.3$ cm^{-1}; that the linear absorption coefficient for grain as estimated from that for water by rates of densities of grain to water $= 0.77 \times 0.074 = 0.057$ cm^{-1}.

Volume (grain and source) $= \pi \times 18.5^2 \times 910 = 980{,}000$ cm³. Volume of source, V, $= \pi \times 1^2 \times 910 = 2{,}860$ cm³. Net volume of grain irradiated/rod $= 977{,}140$ cm³.

$$C_v = 22 \times 4 = 88 \text{ curies/cm}^3$$

$$C = C_v V = 88 \times 2{,}860 = 2.52 \times 10^5 \text{ curies/rod}$$

$$\bar{D} = \frac{KC_vR^2}{2(A+Z)} f(\overline{\theta B})$$

$$K = \frac{0.057 \text{ cm}^{-1}}{0.77 \text{ gm/cm}^3} \times 3.7 \times 10^{10} \text{ dpm/c} \times 0.75 \text{ Mev/Disintegration} \times 10^6 \text{ ev/Mev} \times \tfrac{1}{32} \text{ ion pairs/ev} \times 6.2 \times 10^{-13} \text{ gm-rep/ion pairs}$$

$$K = 39.7$$

$$\bar{\theta} = \phi/2$$

$$\bar{\phi} = \frac{2}{L}\left[\frac{A_1}{2} \ln A_1^2\right] - \frac{2}{L}\left[\frac{A_1}{2} \ln (A_1^2 + L_2) - L \tan^{-1} \frac{L}{A_1}\right] \quad \text{(see ref. 6)}$$

$$A_1 = Z + 17.5$$

$$\nu R = 0.3 \times 1 = 0.3$$

$$\nu Z = 0.18 \text{ (Fig. 9)}$$

$$Z = \frac{\nu Z}{\gamma} = 0.18/0.3 = 0.6$$

$$A_1 = 0.6 + 17.5 = 18.1$$

$$\bar{\phi} = \frac{2}{910}\left[\frac{18.1}{2} \times 2.3 \log 18.1^2\right] - \frac{2}{910}\left[\frac{18.1}{2} \times 2.3 \times \log (18.1^2 + 910^2) - 910 \tan^{-1} \frac{910}{18.1}\right]$$

$$\bar{\phi} = 2.94 \text{ radians}$$

$$\bar{\theta} = \frac{\bar{\phi}}{2} = 1.47 \text{ radians, } 84 \text{ deg approx.}$$

$$\bar{B} = (\mu A + \gamma Z) = (1.00 + 0.18) = 1.18$$

$$f(\overline{\theta B}) = f(84 \text{ deg}, 1.18) = 2.6 \times 10^{-1} \text{ (Fig. 10)}$$

$$\bar{D} = \frac{39.7 \times 88 \times 1}{2(17.5 + 0.6)} \times 2.6 \times 10^{-1} = 25.3 \text{ rep/sec}$$

Exposure time
= total dose/average dose rate
$= 25{,}000/25.3 = 1{,}000$ sec

Weight of irradiated grain per rod
$$= \frac{977{,}140 \times 0.77}{454} = 1{,}660 \text{ lb}$$

Process rate per rod
$= 1{,}660 \times 3{,}600/1{,}000 = 5{,}960$ lb/hr

A 6-ft diameter tank containing 14 unit sources will process $14 \times 5960 = 83{,}500$ lb/hr (Fig. 5)

Total curies $= 14 \times 2.52 \times 10^5 = 3.53 \times 10^6$

Utilization efficiency of source is calculative by the relations 25,000 rep = 0.095 kw-sec/lb; 1 megacurie (0.75 Mev) = 4.45 kw, and 3.53 megacuries $\times$ 4.45 kw/megacurie $\times$ 1/0.095 lb/kw-sec $\times$ 3,600 sec/hr $\times$ % efficiency/100 = 83,500 lb/hr. Therefore, utilization efficiency = 14.7%

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Fast-Coincidence Circuit for H^3 and C^{14} Measurements

This coincidence circuit, with 0.06-μsec resolving time, can count tritium and carbon-14 with 10–15% and 60–70% efficiency. An "upper-gate" discriminator in anticoincidence improves the sample-to-background counting-rate ratio

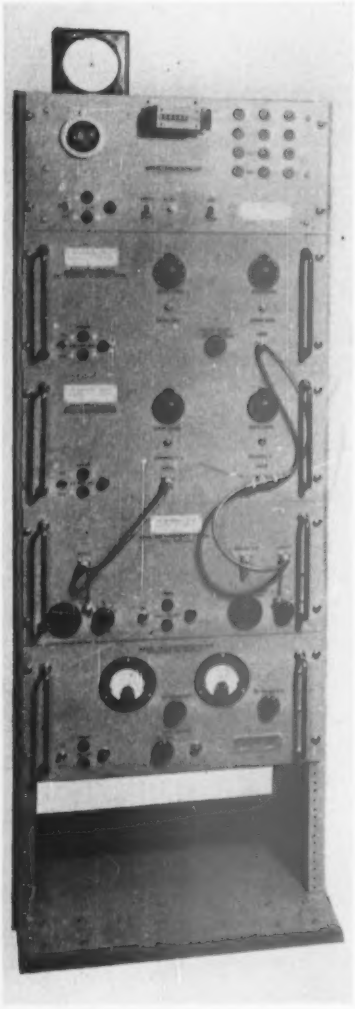

FIG. 1. Coincidence-system components: photomultiplier supply, dual amplifier, dual discriminator, upper-gate discriminator, and scaler at top

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THE DIFFICULTY POSED in tritium and carbon-14 low-level pulse measurements by photomultiplier dark current is conventionally overcome with the use of coincidence circuits. The instrument described here falls into this class. In view of the published results (*1*), it seems worthwhile to report on the equipment used.

The unique features of the instrument (Fig. 1) lie in the speeds attained and in the combination of the elements of the instrument. The elements themselves have arisen from various sources and are not well known, so that it also seems worthwhile to describe them.

Figure 2 is a block diagram of the instrument. The two photomultiplier tubes are fed from a positive, dual, high-voltage supply. The two preamplifiers obtain their supply voltage from the main amplifiers. The overall rise time of the preamplifiers plus amplifiers is 0.08 μsec. Amplifier No. 1 and amplifier No. 2 feed channel 1 and channel 2 discriminators, respectively.

It is important to note that all the discriminators in this equipment have a positive output pulse, which is constant in amplitude and time (or width) and does not vary with the setting of the acceptance level of the discriminator or input pulse shape. This feature makes it possible to feed the discriminator pulses directly to the coincidence-anticoincidence circuit with no further shaping.

Amplifier No. 2 also feeds the "upper-gate" discriminator. This, in turn, feeds the anticoincidence circuit. Thus, if approximately simultaneous pulses are received from channels 1 and 2, but none from the upper gate, a pulse is passed to the "coincidence-out" discriminator.

The coincidence-out discriminator in turn passes a pulse to a 0.5-μsec delay line. If at the end of this time a pulse has been received simultaneously from a G-M tube "umbrella" over the photomultiplier tubes, the pulse is suppressed by another anticoincidence circuit. If no pulse is received from the G-M tube source, the coincidence-out pulse is passed to a scaler and counted.

A switch is also provided so that channel 1 and channel 2 may be counted at will.

The upper-gate discriminator acceptance level is set so that it operates only if it receives a pulse of high amplitude. This effectively eliminates all high-level coincidence pulses from the output.

Circuit Details

Figure 3 is a schematic of the bleeder chain for the photomultiplier tubes and the preamplifiers. A positive high-voltage supply was chosen so that the photocathodes of the photomultiplier tubes could be at ground. If the magnetic shield of the photomultiplier is then at ground, there is no electrical strain across the glass of the photomultiplier in the region of the photocathode. Therefore, any pulse breakdown that may arise from this source

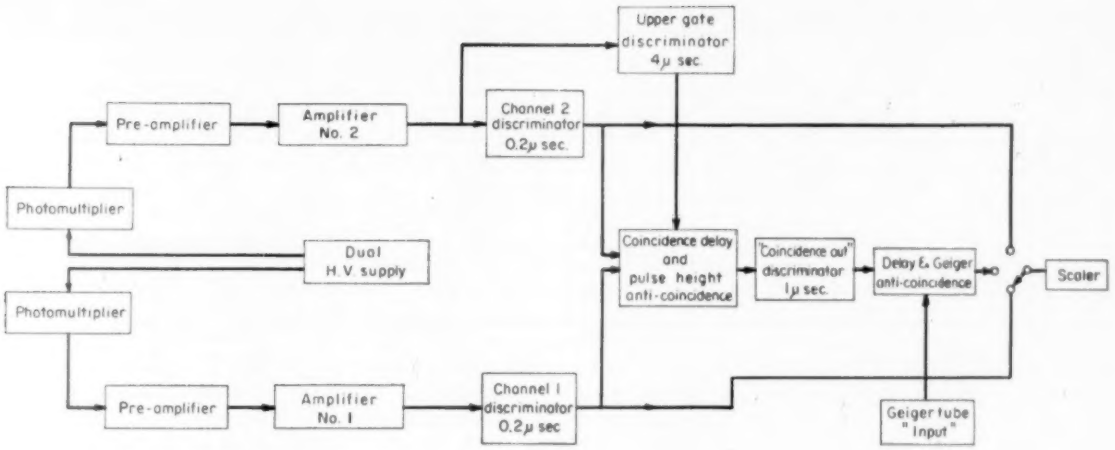

FIG. 2. Coincidence-anticoincidence system

is eliminated. This supply may be any conventional supply provided it has very good stability.

Preamplifier circuit. The preamplifier circuit is conventional. Premium subminiature tubes were chosen so that the preamplifier could be built at the photomultiplier-tube socket to save space and minimize output capacitance of the photomultiplier. Thus the very maximum in pulse height is attained from the photomultiplier, and, with the small photomultiplier-anode load resistance, the decay-time constant is short enough that no further clipping in the amplifier is needed. The cathode resistor of the output cathode follower is placed on the main amplifier chassis.

Main amplifier. Figure 4 is a schematic of the main amplifier. A coarse-gain control is provided by tapping down on the cathode resistor of the preamplifier cathode follower.

The main amplifier consists of three sets of 3-tube cathode feedback loops. Inasmuch as this type of circuit has been discussed by numerous authors (*2*), little need be said of its operation. The total gain is 7,000, and the rise time for 10–90% is 0.08 μsec.

Discriminator circuits. The schematic of the four discriminator circuits is shown in Fig. 5. This circuit was developed at Harwell* and has been modified to use American tubes and components. It is a three-tube, regenerative feedback loop. Regenerative feedback is provided by a common 1,000-ohm anode resistor for tubes V302 and V305. The middle tube of the loop (V304) has a shorted Millen delay line in its anode circuit. It is this delay line plus the d-c biasing of V305 that make possible the constant-width output pulse.

The operation of the circuit may be described as follows: When the positive input pulse over-rides the bias on V302, there is a fast regenerative action. Current through V304 is cut off and a pulse twice the duration of the delay line appears at the grid of V305. A pulse then appears at the output. With a 0.1-μsec delay line, it is 0.2 μsec in duration and about 10 volts in amplitude. When the input pulse recedes, there is again a violent regenerative action. Again there is delay-line clipping (*3*); however, in this case, the pulse is of the opposite polarity. Inasmuch as the cathode of V305 is biased positively, this negative pulse is clipped and does not appear at the output. Thus a pulse of constant duration is obtained at the output regardless of the magnitude of the input pulse. With the circuit constants given, the rise time of this output pulse is 0.05 μsec, and the duration can be varied at will by substituting delay lines with varying delay times.

Coincidence-anticoincidence circuit. Figure 6 is a schematic of the coincidence-anticoincidence circuit. The low output impedance of the Harwell discriminators feed the positive pulses generated to the IN38 coincidence

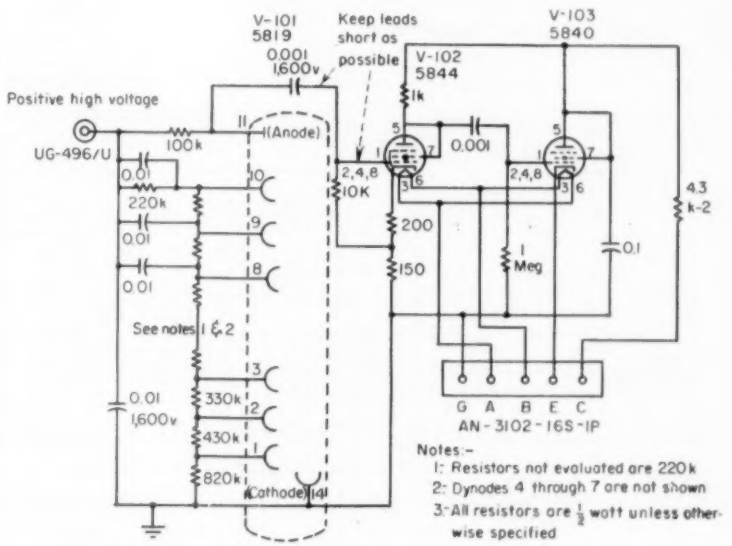

FIG. 3. Bleeder chain for photomultipliers and preamplifiers

* Published by permission of Atomic Energy Research Establishment, Harwell, England.

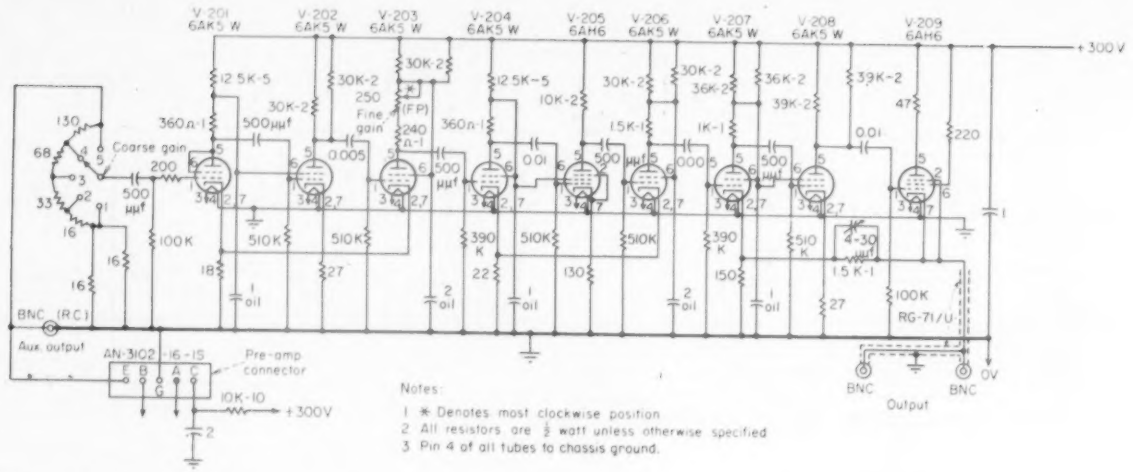

FIG. 4. Main amplifier circuit

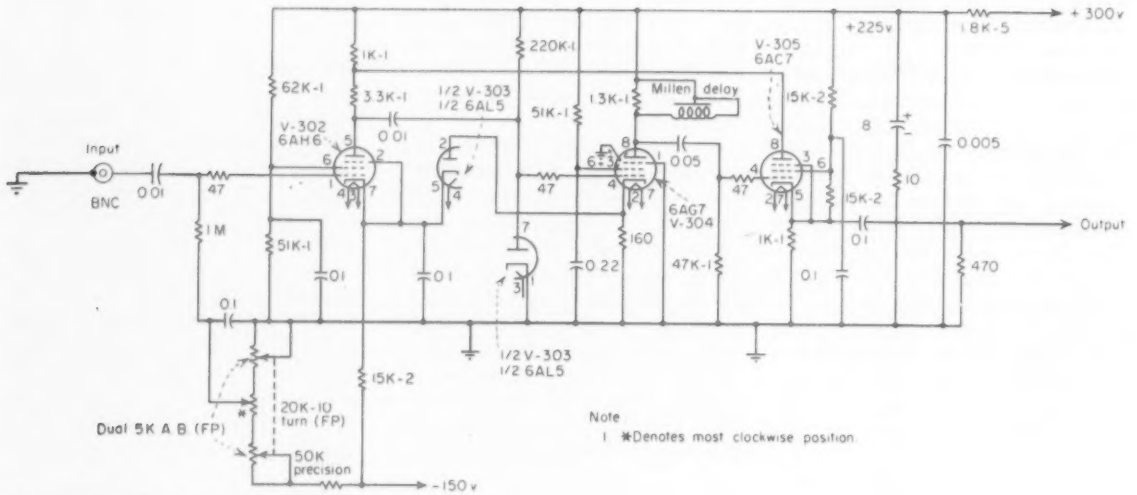

FIG. 5. Circuit used for four discriminators

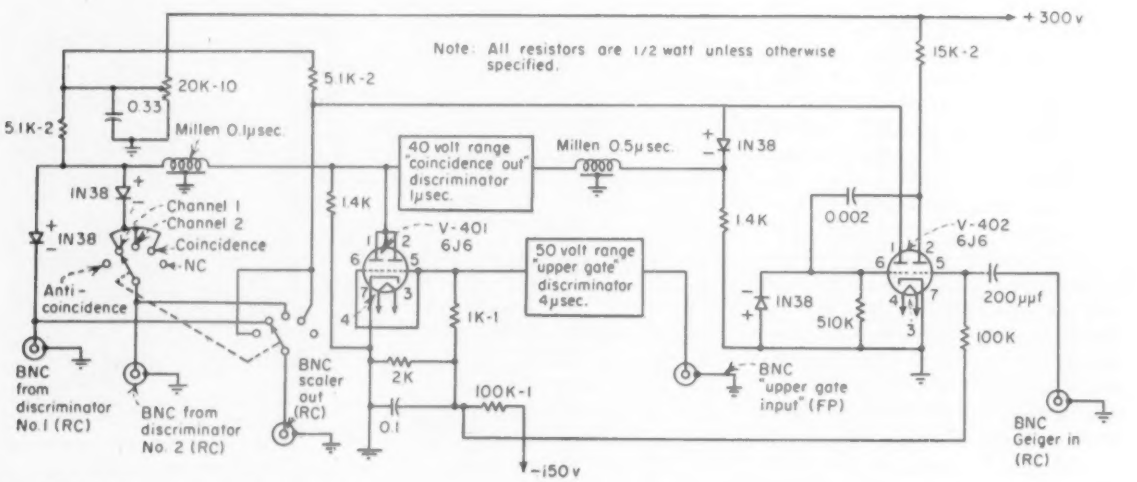

FIG. 6. Coincidence-anticoincidence circuit

diodes. Both diodes have a common anode load and are connected so that they are conducting. A positive input pulse thus cuts them off if it is fed into the cathode end. Because of the characteristics of germanium diodes, cutting off either diode separately only gives a 2-volt output pulse, inasmuch as the other conducting diode holds the voltage down. Cutting both off together gives an 8-volt pulse. The "coincidence-out" discriminator is set so that it only operates on the 8-volt pulse.

The anticoincidence feature is provided by the 6J6 tube in parallel with the crystals. The "upper-gate" discriminator is set to the desired amplitude-rejection level. This discriminator has a 4-μsec output. The relatively long 4-μsec duration is chosen so that the system is blocked when satellite after-pulses appear from the high-energy pulses. When a pulse is received from this discriminator, the 6J6 becomes conducting and effectively short-circuits any pulse that may come from the diodes.

Delay line. The 0.1-μsec delay line following the IN38 crystal output serves two purposes. First, the amplifiers have a finite rise time of 0.08 μsec. Thus, on a large pulse, the upper-gate discriminator cannot operate simultaneously with the coincidence diodes. The delay line, therefore, delays the pulse by sufficient time to allow the upper-gate discriminator to operate and the 6J6 to transfer to a conducting state.

Secondly, its finite bandwidth spoils the rise time of the coincidence pulse. The sides of the output pulse from the delay line thus look similar to a Gaussian curve. The coincidence-out discriminator can be set to just "pick off" the top of this curve, which in essence reduces the time spread between pulses before they can be called a coincidence.

The 1-μsec pulse output from the coincidence-out discriminator is again fed to an anticoincidence circuit consisting of another germanium diode and a 6J6 tube (V402). A pulse from the G-M tube "umbrella" is amplified and inverted. In a like manner to that already described, this inverted pulse is used for anticoincidence with the pulse from the coincidence-out discriminator.

If the two coincident pulses survive the two possibilities for anticoincidence, a pulse is fed to a scaler for counting. The output pulse to the scaler is thus 1 μsec in duration and about 10 volts high. When either channel is being counted, the pulse is only 0.2 μsec in duration. It should, therefore, be ascertained that the scaler used operates on pulses of these specifications.

Procedure for Adjusting

The instrument is best adjusted with a calibrated pulse generator. The bias adjustment on the discriminators is made by a 10-turn potentiometer. In series with the potentiometer is a dual 5K potentiometer. By adjusting this dual potentiometer, it is possible to make the dial on the 10-turn potentiometer direct-reading in terms of voltage-input pulse height. The coincidence-out discriminator is fixed at a level that just detects an actual coincidence when discriminators 1 and 2 are pulsed simultaneously.

Further adjustments are best left to the experience of the experimenter. In counting tritium, for example, it may be desired to set the upper-gate anticoincidence to a lower level than normally used.

Results

The measurement of resolving time is somewhat confused by the existence of "light dark current" (*1*) at low levels of pulse height.

This phenomena is presumed to arise from the photomultiplier dynodes emitting light when they are bombarded by electrons. This light may then produce a small amount of regeneration in the originating tube. If the other coincidence tube is facing the first, a fraction of the light may also impinge on its photosurface.

This difficulty can be avoided by testing the resolving time with a sliding, double-pulse generator.

Inasmuch as a pulse generator of this type with the required pulse duration and spacing was not available, the resolving time was computed from random pulse rates.

With the tubes facing each other and 130,000 counts per minute of random noise in each channel, the resolving time was 0.09 μsec. When a black cloth was dropped between the two tubes, the resolving time dropped to 0.055 μsec. This difference is a measure of the effect of "light dark current." At lower rates, where end-on gamma radiation caused coincidences, with a count in each channel of 56,000 per minute, the resolving time was 0.062 μsec. At higher rates, with a higher proportion of true noise and a count in each channel of 250,000 per minute, the resolving time was 0.047 μsec.

Conclusion

Hayes and Gould (*4*) have shown that, with this equipment and suitable compounds and scintillator, it is possible to count tritium with an efficiency of 10–15% and carbon-14 with an efficiency of 60–70%.*

The equipment itself has been robust in operation and has required little service.

* * *

This work was done under the auspices of the U. S. Atomic Energy Commission.

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3. W. C. Elmore, M. Sands, *ibid.*, p. 182
4. F. N. Hayes, R. Gordon Gould, *Science* **117**, 480 (1953)

* Although Ref. 4 shows efficiencies of 4.6% and 55%, respectively, a private communication from the authors indicates that the correct values are as given here.

NEXT MONTH . . .

. . . a partial listing of the contents of the January NUCLEONICS:

"Plans for Argonne Research Reactor (CP-5)," by S. Untermeyer

"Kinetic Behavior of a Thermal Heavy-Water Reactor," by Arne Lundby and U. Holt, JENER, Norway

"Survey of Laboratory Radioactive Waste Disposal," a Nuclear Engineering feature by H. S. Miller et al., Vitro Corp.

"Radioactive Tracers for Special Melts of Steel," by David Douglas, KAPL

Radioisotopic High-Potential, Low-Current Sources

Batteries using an Sr^{90}-Y^{90} source and a polystyrene insulator provide up to 7,000-volt charging potential at 40$\mu\mu$a. Smaller, lighter, and less expensive to operate than chemical batteries, they offer long life under extreme conditions

By JOHN H. COLEMAN
Radiation Research Corporation, West Palm Beach, Florida

GENERATION OF ELECTRIC ENERGY by collecting the beta particles emitted from a radioactive source with an electrode that is insulated from the source by a solid dielectric has been found feasible with polystyrene as the insulator.

The principle of operation of direct-conversion devices in general can be illustrated by generators utilizing a vacuum dielectric (*1–5*). Two of these devices will be described preliminary to a discussion of models incorporating solid dielectrics.

Vacuum-Dielectric Devices

As early as 1913, Moseley (*1*) attained a high electric potential by collecting the beta particles emitted from a radioactive source suspended in a vacuum. Moseley's apparatus, Fig. 1, consisted of two concentric spheres with a vacuum connection to the outer sphere for evacuation. The center sphere or source electrode was a quartz bulb containing approximately 20 millicuries of radium. The wall of the bulb was sufficiently thin to enable penetration of the emitted beta particles but thick enough to absorb the alphas.

This source of beta electrons was supported by a thin insulating quartz rod attached to the inside wall of the outer sphere that collected the electrons. The inner and outer sphere were covered with a conducting coating of silver, forming the anode and cathode, respectively. Any potential difference between the electrodes was measured by an attractive disk-type electrometer located in the mouth of the vacuum connection.

On evacuation of the interelectrode space, Moseley repeatedly measured around 150 kv on the source electrode before internal flashover discharged the device. A simple capacity-charging relationship was noted after each discharge for a beta charging current of about 10^{-11} ampere.

In 1952, Linder (*2*) published results on two vacuum devices similar to Moseley's, using a Sr^{90}-Y^{90} fission-product source. In one device, with

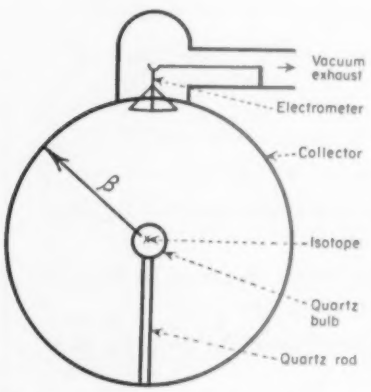


FIG. 1. Moseley's vacuum generator

Specifications of Solid-Dielectric Batteries

	Battery model	
	B-50	*D-50*
Source	10-mc Sr^{90}-Y^{90}	10-mc Sr^{90}-Y^{90}
Insulator	Polystyrene	Polystyrene
Collector	Aluminum	Aluminum
Shield	Lead	Lead
Potting compound	Biwax	Polystyrene
Output current ($\mu\mu$a) at zero voltage	40	40
Current-collector efficiency	33%	33%
Maximum charging voltage (volts)	6,000 (after 2 months)	7,000 (after 2 weeks)
Total volume (in.^{3})	4	1

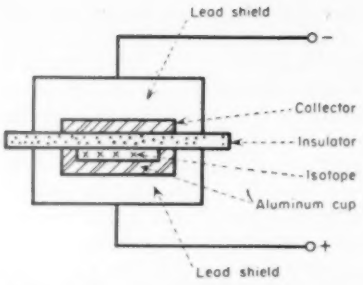


FIG. 2. First experimental model of generator with solid insulator

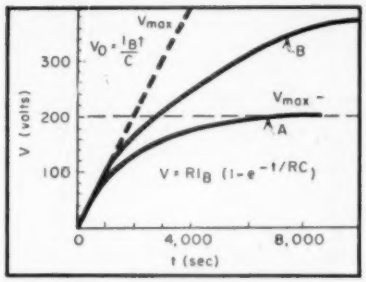


FIG. 3. Charging voltage vs time for 0.002-in. polystyrene after irradiation for few minutes (A) and several hours (B)

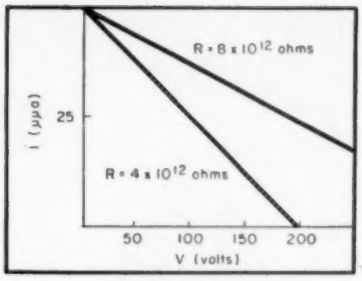


FIG. 4. Current-voltage characteristics of 0.002-in. polystyrene sheet under conditions of Fig. 3

improved vacuum techniques and electrode design, a potential difference of 365 kv was obtained. In the other device, a direct electrical connection to the source electrode was made through an external insulator that formed part of the vacuum enclosure. A somewhat lower voltage was obtained with this device due to surface leakage on the external part of the insulator exposed to the atmosphere. A capacity-charging curve across a resistive load was measured by Linder for an equivalent circuit of a beta current source, a capacity, and an internal resistance in parallel with the external load. The internal resistance was a combination of surface conduction across the insulator bushing and some conduction through the vacuum by cold emission or residual gas.

Solid Dielectric

In 1951, a project was started at this laboratory to develop a solid insulator that could be substituted for the vacuum dielectric in the direct-conversion generator to increase reliability.

The literature at that time stated, however, that insulators were both lowered in electrical resistivity (*6*) and physically degraded (*7*) by ionizing radiation. These effects are not limitations in the vacuum generators since insulator bushings can be shielded from the radiation. On the other hand, when a solid is substituted for a vacuum, the radiation must penetrate the solid dielectric itself for operation of the device.

Thus, to determine the feasibility of a solid-dielectric type of radioactive battery, a test program was started on commercially available insulators.

Experimental Data

For geometrical simplicity, tests were made using flat sheets of insulation between the faces of cylindrical source and collector electrodes, as shown in Fig. 2. As a beta source, 25 mc of Sr^{90}-Y^{90} were deposited in an electrode formed by an aluminum cup covered with aluminum foil. An aluminum disk, opposite this source electrode, collected the beta particles after penetration of the insulator. Lead shielding was used around the aluminum collector and aluminum source electrode to reduce the bremsstrahlung below tolerance at the surface.

In operation, the beta current collected through a 0.002-in.-thick polystyrene insulator was measured with an electrometer to be about 50×10^{-12} ampere at zero voltage. The total beta current emitted from 25-mc Sr^{90}-Y^{90} is 300×10^{-12} ampere; however, one half of the current is emitted in an opposite direction from the collector and is absorbed in the aluminum cup. The remaining loss of current is due to absorption in the thin aluminum sheet covering the cup and in the insulator, itself.

Charging voltage. The open-circuit charging voltage was measured as a function of time by an electrometer voltmeter with negligible capacity. The resulting voltage, V, (the lower curve in Fig. 3) for the 0.002-in.-thick polystyrene insulator showed an exponential rise with time, t, to a maximum of 200 volts.

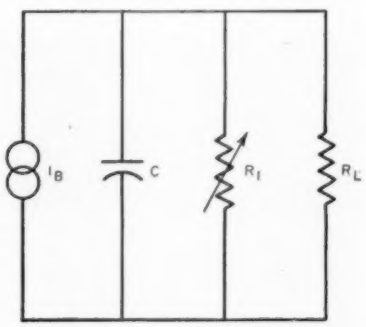


FIG. 5. Equivalent circuit of battery using solid dielectric that increases in resistance with irradiation time

As in the case of the vacuum generators of Moseley and Linder, capacity charging of this type is given by the equation

$$V = RI_B(1 - e^{-t/RC}) \qquad (1)$$

where R is the total internal and external resistance in parallel, C is the total capacity, and I_B is the beta current. The maximum charging voltage, V_{max}, for $t \gg RC$ is

$$V_{max} = RI_B \qquad (2)$$

Next, the initial rate of charge is found by expansion of Eq. 1 for $t \ll RC$ to be independent of R and given by

$$V_0 = \frac{I_B}{C}t \qquad (3)$$

Thus, from Eq. 2, for V_{max} of 200 volts and I_B of 50×10^{-12} ampere, R is 4×10^{12} ohms.

Irradiation effect on insulator. After several hours, a second measurement of the charging voltage as a function of time was made, and V_{max} was found to have increased to 400 volts, as shown by the upper curve of Fig. 3, indicating an increase in insulation resistance to 8×10^{12} ohms while the initial charging rate remained the same. Consequently, a direct measurement of internal resistance, R_I, was made by applying an external voltage to the generator terminals and recording the resulting current with the electrometer.

The current-voltage characteristics for an unused 0.002-in.-thick polystyrene sheet is shown by the lower curve of Fig. 4. The straight line indicated an ohmic resistance of R_I =

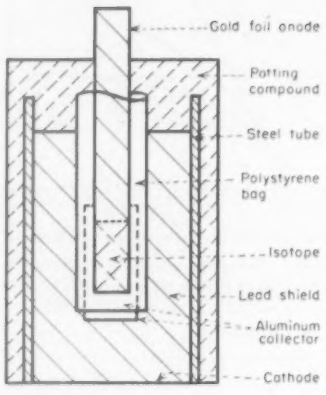


FIG. 6. Model B-50 generator. Assembled, unpotted battery at left

4×10^{12} ohms, which can be calculated by inverse of the slope or

$$R_I = \frac{V}{I - I_B} \qquad (4)$$

On continued irradiation, the current-voltage characteristic (upper curve of Fig. 4) showed a decrease in slope or increase in resistance to $R_I = 8 \times 10^{12}$ ohms, both values of R agreeing with the results in Fig. 3.

Next, to measure this apparent change in resistance after irradiation, a fresh sheet was inserted between the electrodes of Fig. 2 and a constant voltage applied while the source was covered with an absorber. The absorber was removed after the normal polarization current decreased to a low value (the corresponding volume resistivity $\rho = 10^{15}$ ohm-cm) and the induced current recorded. The calculated resistivity was found first to drop to about 10^{16} ohm-cm, decrease further for a few minutes to a minimum of about 10^{15} ohm-cm, and then actually increase in resistance after one day with approximately the square root of the time. Details of this effect were given in a previous paper (*8*).

Thus, the equivalent circuit in Fig. 5 of a generator using a solid insulator can be deduced from Eq. 1 and from the observed induced conductivity effect in solid insulation. This circuit is seen to be similar to the vacuum generator except that the internal resistance R_I is a variable, being a function of the total time of irradiation and of the incident beta-current density. All good insulation (i.e., unirradiated $\rho > 10^{16}$ ohms-cm) showed this effect; however, an accelerated life test using a 250-mc source eliminated all plastic insulators but polystyrene due to physical degradation. For example, the fluorocarbons Teflon and Kel-F increased in resistance for a few weeks, then became brittle, and shorted the electric circuit; polyethylene increased in resistance for a week, then began to decrease due to slow degradation. Polystyrene, on the other hand, has increased in resistance for over 1 yr.

On the basis of these results, the test source of Fig. 2 was potted in plastic and demonstrated in January, 1952, as a radioactive battery. Since that time, models B-50 and D-50 have been built, reducing the size and weight and increasing the safety for the same current output of 50 $\mu\mu$a.

Battery Design, Characteristics

Model B-50 is shown in Figs. 6 and 7. A beta source of 10 mc of Sr^{90}-Y^{90} is welded between two strips of 0.0005-in.-thick gold foil, 2 in. long and $\frac{1}{4}$ in. wide. The active area extends $\frac{1}{4}$ in. from the bottom end and is surrounded by a "U"-shaped aluminum collector, $\frac{1}{8}$ in. thick, which is supported by a lead shield.

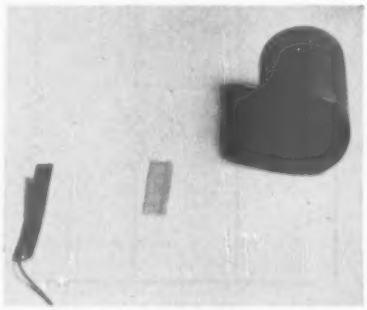


FIG. 7. Parts of B-50: shield, insulator, and gold-encased source

A slot for insertion of the source and insulator was formed by pouring the lead around a stainless-steel jig, which held the aluminum collector in position in a steel tube. The jig was removed after the lead cooled and the source was placed in two polystyrene bags and inserted in the slot. One bag, $\frac{3}{8}$ in. wide and $1\frac{1}{4}$ in. long, was inside a larger bag, $\frac{1}{2}$ in. wide and $1\frac{3}{8}$ in. long. Both bags were made by folding 0.005-in. Plax polystyrene along the long dimension and heat sealing along a $\frac{1}{8}$-in., "L"-shaped border, leaving the top open. "Biwax" potting compound was poured around the outside of the unit, and the output characteristics were measured.

First, the average output current for twenty-five batteries at zero voltage was found to be $I_B = 40 \times 10^{-12}$ ampere out of a total available current of 120×10^{-12} ampere, a 33% current-collection efficiency. Most of the 67% loss was due to absorption in the gold foil of most of the Sr^{90} beta particles and some of the weaker Y^{90} beta particles.

The initial rate of charge of the output voltage was then measured across an electrometer voltmeter to be 1.2 volts/sec and the capacity was calculated for Eq. 3 to be $C = 30\ \mu\mu$f. This capacity is slightly higher than the capacity of 25 $\mu\mu$f measured on a bridge, since a high-resistance contact to the surface of the insulator by ionization of the air between the source and collector reduces the effective spacing between the source and collector electrode. Also, polarization current and trapped beta particles were found to be a significant part of the current when the voltage was changed. For example, it was necessary to wait several minutes on shorting the terminals before the current reduced to its original value at zero voltage.

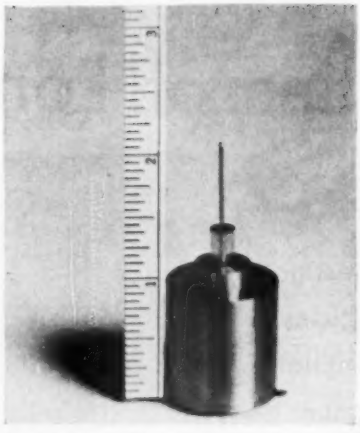
The maximum charging voltage across an electrostatic voltmeter after two months was increased from a few hundred volts to 6,000 volts, which from Eq. 2 corresponds to an internal insulator resistance of 1.5×10^{14} ohms. Model B-50 had a higher current-collection efficiency than the original unit of Fig. 2, since the collector electrode surrounds the source. The dense gold source electrode, however, in-

creased the bremsstrahlung and, consequently, the shielding.

Model D-50. In the third model, D-50 (Figs. 8 and 9), the radioisotope is deposited directly in the polystyrene insulator, which is machined in the form of a cup $\frac{3}{16}$ in. in diameter and $\frac{3}{8}$ in. long with a $\frac{1}{32}$-in. wall. Contact is made to the isotope source by a 0.005-in.-diameter monel-wire loop, which is soldered to a $\frac{1}{8}$-in.-diameter copper rod held in a $\frac{1}{4}$-in.-diameter polystyrene plug. A solvent such as toluene is used to seal the open end of the capsule to a groove in the plug after the isotope is inserted. The plug and capsule fit in a cylindrical aluminum collector $\frac{3}{8}$ in. in diameter and $\frac{3}{4}$ in. long that is held in the lead shielding and copper tube. The wax potting compound used in the B-50 was replaced with polystyrene to reduce surface leakage. When the complete battery was assembled, swab tests were made to detect any radioisotope leakage. The measured radiation of the D-50 was approximately the same as model B-50; however, the volume, including shielding, was reduced from 4 in.^{3} to 1 in.^{3} by the elimination of the gold source electrode. In the D-50, the only dense material within range of the beta particles is the monel wire, which has a small cross-section.

Next, the electrical characteristics were taken as in the case of the B-50. The current at zero voltage was again 40 $\mu\mu$a; the battery capacity was approximately 5 $\mu\mu$f for a charging rate of 5 volts/sec across an electrometer, which added 3 $\mu\mu$f; and the maximum voltage was 7,000 volts after two weeks shelf life. This beta current represents a 33% collection efficiency of the 120×10^{-12} ampere emitted from the isotope. Most of the lost current in this case is absorbed in the $\frac{1}{32}$-in.-thick insulator wall. This thickness, however, increases the breakdown voltage to approximately 30,000 volts. For special applications where the maximum voltage required is only a few hundred volts, the insulator thickness can be correspondingly reduced to obtain an increase in current (at a sacrifice of mechanical strength). Also, for lower current applications, the shielding can be decreased for the same external radiation.

The output voltage decreased when a battery was exposed to room atmosphere in a fully charged condition for more than a few hours due to electrostatic precipitation of dust and, consequently, surface conduction across the external insulation. Contamination of the polystyrene surface was less serious than in the case of the wax potting compound. In either case, however, the dust could be removed with soap and water followed by a thorough drying.



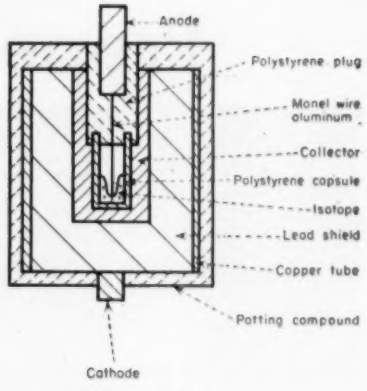


FIG. 8. Model D-50 generator. Assembled, unpotted battery at left

Development work is continuing on improving the mechanical seals to decrease the possibility of any isotope leakage. It appears, however, that the present geometry gives about the minimum volume with a 10-mc source for an external radiation that is below tolerance at the surface. For lower currents, the shielding can be scaled down accordingly.

Applications

Batteries using radioisotopes as an energy source offer, in principle, the advantages of long life under extreme operating conditions, as the nuclear process itself is essentially unaffected by temperature or pressure. The half-life of the Sr^{90}-Y^{90} isotope is approximately 25 yr; however, a wide choice of half-lives is available. The extrapolated life of the polystyrene insulation from the 250-mc tests has exceeded 25 yr for the 10-mc batteries, or 250 yr for a 1-mc battery. As no chemical reactions or solid-state effects are used in the power generation, the insulation appears to be the only critical feature.

Thus, for applications requiring small currents, such as ionization chambers, these batteries should offer the advantages of smaller size, less weight, and lower cost,* since most of the power available from conventional chemical batteries is not used. Also, in applications requiring operation over a period of many years at low temperatures, these batteries appear to be more reliable than batteries that depend completely or in part on a chemical reaction.

FIG. 9. Parts of D-50: shield, aluminum collector, polystyrene cup insulator, and polystyrene plug with wire anode lead

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* It is estimated that an ionization chamber power supply producing up to 10,000 volts with a charging current of 10 $\mu\mu$a could be manufactured in quantity for under five dollars at the current price of Sr^{90} of fifty cents per mc.

Properties of Long Columns

Scintillation columns were investigated for measuring high-energy particles. With terphenyl solution as scintillator, a 60-cm column produced maximum pulse heights with cosmic rays. Transparent glass vessels are best for long columns

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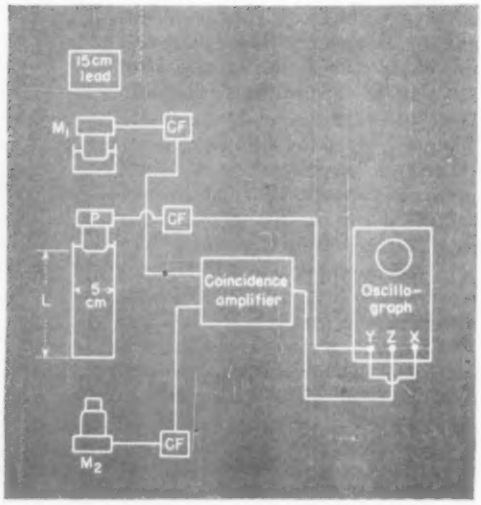

FIG. 1. Arrangement of scintillator and components

THE EFFECTIVENESS OF LONG COLUMNS of scintillating liquids for detecting high-energy particles has been explored with a telescope arrangement excited by cosmic rays. Although measurements have been made on one liquid only* (viz., phenylcyclohexane with 3 gm/liter of terphenyl and very small amounts of diphenylhexatriene), the method† is suitable for study of other scintillating liquids.

Experimental Arrangement

The method consists essentially of obtaining on an oscillograph screen a trace whose length is proportional to the light produced by cosmic rays when passing almost vertically through a column of a scintillating liquid.

The experimental arrangement is shown in Fig. 1. The cosmic rays enter from above and first pass through 15 cm of lead, which serves to filter out the soft shower-producing component. They then pass through two monitors, M_1 and M_2, with the column of liquid, L, between them. The monitors are connected through amplifiers to a coincidence circuit, which turns on the oscillograph beam. By such a coincidence arrangement, light flashes of fairly equal size are produced because only those tracks are recorded that have travelled the full length of the liquid column. The monitors are scintillating liquids or crystals. Photomultipliers (RCA 5819) are used throughout so that the monitors and liquid must be within a light-tight enclosure.

In the usual type of cosmic-ray measurement, many particles per minute are counted, and one spurious pulse more or less does not make too much difference. When, however, one records only one or two per hour, as is the case for the very long columns where only those coming down vertically within a narrow 2-deg cone are recorded, then spurious counts should be avoided as much as possible. In this respect, the use of batteries instead of an electronic power supply for the photomultiplier proved advantageous.

Oscillograph. A DuMont type 294A oscillograph, which has a maximum Y sensitivity of about 0.7 volt/in., was used with an accelerating voltage of 12,000 volts.

The photomultiplier P, which looks into the liquid column, does not need a preamplifier, since the output, even with the low multiplier voltage used, is sufficient to operate directly the amplifiers of the X and Y axes. On the other hand, for positive action of the coincidence circuit, preamplifiers with a voltage gain of twenty are used in the monitor circuits.

For recording the pulses, 35-mm film, moving at a speed of 6 in./hr,‡ was used to photograph the cathode-ray screen (Fairchild oscillograph camera). The number of particles recorded varied from about 1 to 7 per hour. However, the low film-speed limit was desirable, with the fast Kodak Super XX film and f/2.8 lens opening, to avoid fogging the film by the small general glow produced by light from the filament and stray electrons on the oscillograph screen.

Photomultiplier and cathode follower unit. To cut down on spurious discharges of the photomultiplier, particularly in damp summer weather, the negative potential on the cathode of the tube should not be made too high—between 500 and 600 volts are sufficient. The potential difference between all dynodes was the same. The

* H. Kallmann, M. Furst, NUCLEONICS **8**, 32 (1951).

† This method is a modification of that reported at the April, 1952, Washington meeting of the American Physical Society.

‡ Very convenient here are small gear boxes made by the Metron Instrument Company.

§ Burgess type 5308, 45-volt "B" batteries lasted at least one year under normal use.

# of Scintillating Liquids

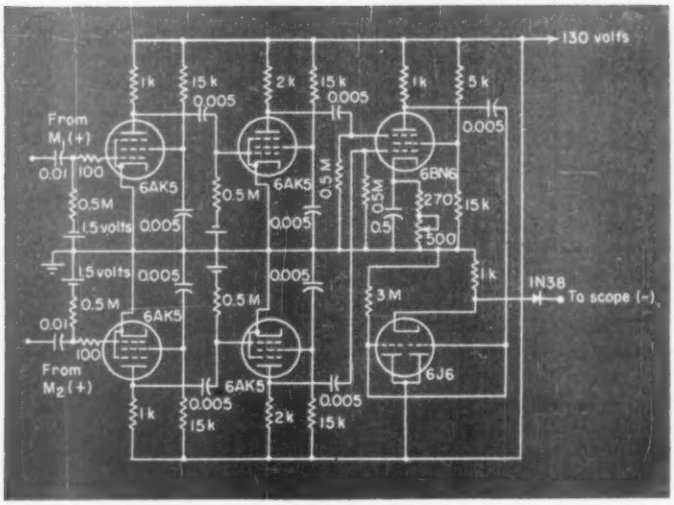

FIG. 2. Preamplifier, coincidence, and pulse-lengthening circuit

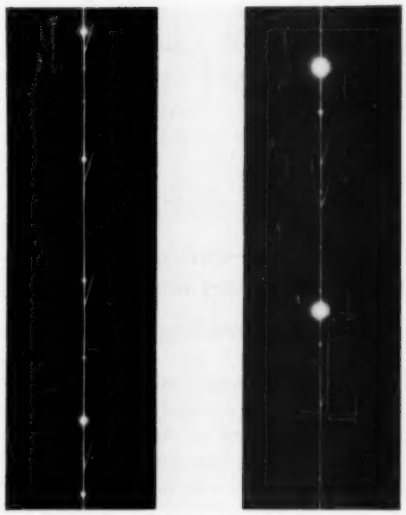

FIG. 3. Typical tracks recorded by oscillograph

voltage was checked frequently and small cells added when the voltage§ dropped as the cells aged.

To operate the coincidence circuit (Fig. 2), it was desirable to obtain positive pulses from the photomultiplier. This was done by taking the pulse off dynode No. 10, rather than the anode, and supplying the anode potential by a separate 90-volt battery.

A very short connection allows the pulses to enter a cathode follower (6J6), which presents a very high impedance load to the photomultiplier and at the same time acts as a low-impedance source for any further amplification, allowing the use of shielded cables. The decay time of the pulse in this circuit is about 10 μsec. Units of this type were used at M_1, M_2, and P. For pulses that are close together in time, such decay constants would be too long. However, in our case (1–7 pulses/hr), the chance of two pulses separated by less than 10 μsec actuating the circuit is negligibly small.

Preamplifier and coincidence circuits. The 6BN6 gated-beam tube (Fig. 2) requires positive, 5-volt input pulses for successful operation. This means that the pulses from the photomultiplier unit must be amplified. Two pentode stages give an amplification of about 20 and do not reverse the direction of the pulse.

As shown in Fig. 2, the two pulses from M_1 and M_2 are passed through two similar amplifiers and then to the two grids of a 6BN6 tube. Coincident pulses give an output from this tube that is passed on to a cathode follower and a pulse-lengthening device using a rectifying crystal (1N38). Pulse lengthening assures full beam intensity for the total duration of the pulse from the liquid scintillator (about 10 μsec). Of course, the intensifying pulse must not be lengthened too much to avoid missing pulses. Even at the maximum counting rate used in these experiments, this chance is very small.

Oscillograph Recordings

The pulses from the photomultiplier, P, are adjusted to give as large a Y-deflection as possible on the oscillograph without overloading. The Y-deflection was linear with applied pulse voltage for Y-deflections up to about 1.8 in. For the longest liquid column, the linearity criterion was satisfied with a potential difference of 520 volts applied to P.

The undeflected spot can be adjusted to be just faintly visible. Thus, when the camera is running, this spot gives a zero line in the Y direction. To distinguish the pulses clearly from the zero line, the entering pulse actuates the X-axis as well as the Y-axis of the oscillograph. Since the X-channel has about $\frac{1}{4}$ the sensitivity of the Y-channel, a track will make an angle of about 14 deg with the Y-axis and thus can be clearly distinguished (Fig. 3). The y component of these observed deflections is then used as a measure of the amount of light collected.

Results

For short liquid columns having a length about equal in diameter to the cathode surface of the RCA 5819 (about 2 in.), the silvered outside surface of a transparent vessel, such as a glass beaker or a glass bowl, was most effective. White (magnesium oxide)¶ surfaces were less effective for the wavelengths of this emitted light.

For γ-rays measured with slightly longer scintillation columns having completely silvered, cylindrical walls, the light pulses were actually halved in size when the length of the liquid column was increased from 5 to 8 cm. This loss of light probably results from the many more reflections brought about by the longer tube. For cosmic

¶ We used a high reflectance paint furnished us by the duPont Co.—#P-1705-2A.

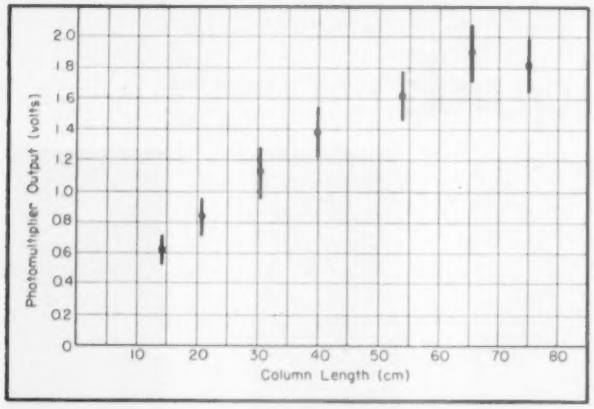

FIG. 4. Photomultiplier output for different lengths of liquid column

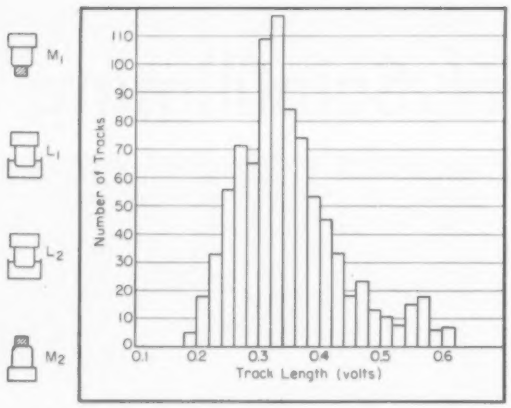

FIG. 5. Track distribution. Monitor arrangement at left

rays, there is a 20% increase in pulse size.

For very long lengths, metallic reflections should be avoided. The best results are obtained by making use of total internal reflection from the glass-air surface of the unsilvered side walls. In addition, the flat bottom of the glass cylinder is silvered on the outside to reflect the light back.

As the column becomes longer, the collected light may become weaker because of the absorption in the liquid. The purpose of the diphenylhexatriene in the solution was to shift the fluorescent light emission from the terphenyl to longer wavelengths to which the photomultiplier is more responsive, and for which the absorption in a long liquid column is smaller.

The results for various lengths are shown in Fig. 4. The ordinates represent the positive voltage pulse produced at the output of the photomultiplier between anode No. 10 and ground, across a resistance of 0.5 megohms, when 520 volts are applied to the 5819. The maximum pulse size under these conditions is $\sim$ 1.8 volts.

The collected light is not proportional to the tube length, and, in fact, when using this particular scintillating liquid, there is no increase in the collected light for thicknesses greater than about 60 cm. The reason for this is probably to be found in the absorption or in the unevenness of the cylindrical surface with regard to critical angle, or in some other process at present not understood. By removal of the reflecting silver coating from the bottom, it was possible to show that about 18% of the light was contributed by reflection from the bottom in the case of the 75-cm tube, whereas this amount became 38% when the column length was decreased to about 15 cm. Overloading of the photomultiplier due to space charge, by the extraordinarily large pulses, could also contribute to the saturation observed. For a 3-cm liquid column, radium γ-rays give a maximum deflection about $\frac{1}{2}$ to $\frac{1}{3}$ of that obtained for cosmic rays when passing through the same liquid. This means that for the long tubes the cosmic-ray pulses are larger than the γ-ray pulses experienced in short columns by a factor of $\sim$ 35.

The measured scatter in the values of Y is indicated by the vertical lines in Fig. 4. The length of these vertical lines represents twice the average of the absolute value of the difference from the mean. It is interesting that the observed scatter is almost the same for the short as for the long columns.

Each point represents the average of about 200 tracks. For the shorter tube lengths, there is no difficulty in obtaining such a number of tracks, but for the long tubes, when the monitors are separated by a distance of approximately 100 cm, one obtains only about 1 track every hour. Such an analysis is made, however, for a slightly different arrangement where at least 1,000 tracks were measured for a short liquid column (described later).

The scatter represented in Fig. 4 is real and is due to many causes, such as: (1) Non-uniform sensitivity of the cathode surface of the photomultiplier. (2) Difference in path of the rays through the telescope. (3) Different types of processes involving the ionization and energy absorption in the liquid. (4) Effect of side showers.

Since the amount of scatter stays approximately the same (the per cent value decreases for the longer column), the effects of (1) and (2) are probably small. In regard to (3), no reliable calculations have been made up to the present time. We have tested the effect of side showers (4) to some extent. By displacing the upper and lower monitors sufficiently out of vertical line with the liquid column, no tracks should be recorded if there were no side-shower effects. For the long tubes (20–40 cm), about 20% of the measured tracks were due to side showers, whereas, for a short column of about 3 cm, this figure is remade to about 4%.

Track-Length Distribution

In another experiment, a large amount of data was collected on the distribution of track lengths for one particular length of liquid. The arrangement for this experiment (Fig. 5) was similar to that shown in Fig. 1, except that two short liquid scintillating columns (L_1 and L_2) were placed between the monitors. The pulses that were produced in the short liquid column, L_1, of length 2.6 cm, were measured. Since the telescope arrangement was shorter, more tracks could be measured in a shorter time. When only one monitor, M_1, is used, the resultant distribution in length is shown in Fig. 5. With both monitors, M_1 and M_2, the distribution was found to be not very different, even though the soft component had been largely removed by a layer of lead 15 cm thick.

* * *

This work was sponsored by the Signal Corps Engineering Laboratory, Evans Signal Laboratory, Belmar, N. J., contract No. DA-36-039SC-42626.

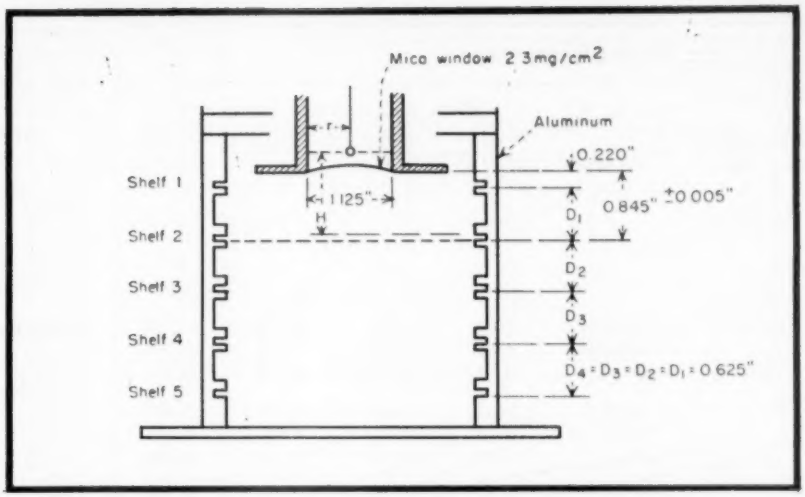

FIG. 1. G-M tube support and shelf assembly for beta counting

Evaluating

Beta Energy Dependence in End-Window G-M Tubes

This method can be used to obtain a good approximation to absolute beta counting without the need for determining each of the many factors involved. Essentially, it is a method for correlating results from different counters

By U. L. UPSON
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IN ANALYSIS of beta counting data derived by means of mica-window G-M tubes, it frequently is desirable to compare rates obtained at different geometries or on different instruments, or both. A number of fundamental investigations of scattering and absorption effected by the source and its surroundings bear on this problem (*1–8*), but the work described here was directed toward determination of empirical factors for rapid correlation of counting rates under standard conditions encountered in routine counting.

To insure reproducible geometries, all beta counting instruments in this laboratory are equipped with identical shelf supports and G-M tubes, as shown in Fig. 1. To minimize the effects of differences in the efficiencies of different tubes, all counts are normalized to a standard counting geometry, or yield, of 7.5% on the reference (2nd) shelf for a standard source of RaDEF mounted on platinum and covered with 9 mg/cm² of cellophane tape.* Only the 1.17-Mev RaE beta is counted from this source, since both the RaD beta (0.018 Mev) and the RaF alpha are totally absorbed by the cellophane tape.

A previous attempt to correlate counting rates obtained from the different shelf positions had been based on

Geometry Definitions

In this article, these definitions apply:

Counting geometry (or yield) = cpm/dpm

Geometry (or physical geometry, calculated geometry) = $\frac{\text{equivalent solid angle}}{4\pi}$

Efficiency = $\frac{\text{counting geometry}}{\text{physical geometry}}$

* In practice the U.S.N.B.S. calibrated RaDEF standard is replaced by long-lived U_3O_8 standards that have been evaluated in terms of their RaE equivalence on these instruments on the reference shelf. These secondary standards are used to obtain daily checks on the efficiency and stability of each instrument.

TABLE 1—Relative Counting Geometries

Max. beta energy (Mev)	*Mounting*	*Ratios of observed net counting rates*			
		Shelf 1 / Shelf 2	*Shelf 3 / Shelf 2*	*Shelf 4 / Shelf 2*	*Shelf 5 / Shelf 2*
0.054(5.0 mg/cm²)*		∞			
0.065(6.9 ")*			0		
0.075(8.8 ")*				0	
0.084(10.7 ")*					0
0.223(Pm^{147})	Glass/air	4.44	0.346	0.152	0.078
	Glass/Al	4.06	0.361	0.164	0.084
	Pt	3.97	0.352	0.155	0.079
0.77(Tl^{204})	Glass/air	3.33	0.441	0.244	0.154
	Glass/Al	3.28	0.452	0.247	0.158
	Pt	3.34	0.426	0.230	0.142
1.53(Y^{91})	Glass/air	3.27	0.456	0.253	0.165
	Glass/Al	3.16	0.464	0.264	0.173
	Pt	3.08	0.453	0.260	0.169
RaDEF (covered)	Pt	3.11	0.418	0.227	0.144

*Beta energies of range equal to air-mica window path from lower shelf.

TABLE 2—Calculated Physical Geometries
r = radius of G-M tube window = 0.5625 in. *p* = radius of source = 0.6 *r*

Shelf	*Source distance*		H/r	*Geometry (%)*	*Relative geometry*
	To window (in.)	*To sensitive zone (H)*			
1	0.170	0.30_8	0.54_8	23.6	3.51
2	0.795	0.93_3	1.65_9	6.74	1.00
3	1.420	1.55_8	2.77_0	2.88	0.427
4	2.045	2.18_2	3.88_1	1.56	0.232
5	2.670	2.80_8	4.98_8	0.96_6	0.143

the observed counting rates for this standard. But the ratio between the counting rates on two different shelves obtained for the RaDEF standard does not necessarily apply for other sources. This discrepancy arises from differences in the maximum energies of the emitters and in the energy distributions involved. The effective beta spectra of different samples vary not only with the emitters present, but also as a result of scattering and absorption, both within the source and external to the source.

A program was undertaken to determine the effects of these factors upon the counting rates obtained for beta emitters of different energies. The immediate objective of this study was to determine the relative counting rates at the different shelf positions for a number of beta emitters covering a range of maximum energies, for various routine methods of mounting.

Applicability of such data to other emitters is necessarily dependent upon the comparability of the beta spectra involved. Thus, it was desirable that the reference sources used be essentially free from gamma emission and that they be "typical" in their beta spectral distribution, that is, that in each case the spectrum should not differ greatly from that of an allowed transition. Such a spectrum has an average energy equal to about 0.40 of the maximum energy, depending upon the values of Z and E_{max} (*9–13*). The emitters selected were Pm^{147}, Tl^{204}, and Y^{91}, having maximum energies of 0.223, 0.77, and 1.53 Mev, respectively. All were assumed to be essentially pure beta emitters.† All appear to exhibit some degree of forbiddenness, but Fermi plots of the spectral data indicate spectra having very nearly the allowed shape in all cases (*12, 16–22*). In contrast, RaE has been shown to have an average beta energy of only 0.28 E_{max}, and therefore cannot be considered as a "typical" beta source (*12–14, 21, 23, 24*). The evidence of the present study supports this conclusion.

† X-rays (approx. 74 Kev) have been reported for Tl^{204} (*15*), and might be present in other of these emitters. However, the efficiency of a G-M tube is relatively low even to X-rays, as compared to its beta efficiency.

Experimental Procedure

The G-M tubes used in this study were argon (90%) -ethyl alcohol (10%) filled at 102 mm Hg, brass-shell tubes, having graphite-coated mica windows of 2.3 ± 0.2 mg/cm² thickness and 1.125 in. diameter. Samples were prepared on glass, aluminum, and platinum mounts. The glass mounts were standard 1-in. watch glasses and were counted both over air (supported by a card with a hole in it) and over aluminum (on a dimpled holder conforming to the curvature of the glass). The metal mounts consisted of ⅞-in. diameter, flat disks of 0.005 in. thickness. All were supported so as to give the same mean distance from the source to the tube window, for any given shelf position.

Samples were deposited, as nearly as possible, as uniformly distributed circular sources of 0.675 in. diameter. All samples were counted uncovered. The data obtained for emitters deposited directly on aluminum were discarded because of poor precision, probably due to variable absorption by dissolved aluminum. The quadruplicate direct mount deposits of the other sources showed a reproducibility of ±3% or less (standard deviation). Counting rates on each source were determined to a statistical precision of better than ±0.5% at the 99% confidence level for the averages of the normalized net rates obtained on four different instruments.

The observed data, expressed for each source type as the ratio of the net counting rate on each shelf to that on shelf 2, are given in Table 1. The same data, for glass-over-aluminum and for platinum mounts, are shown in Fig. 2, in which the curves are plotted through the three experimental points and through the zero intercept at the beta energy corresponding in range to the air-mica window path from the lower of the two shelves being compared. The shelf 1/shelf 2 curve is not

included in the figure because of its inverted form, but its shape was similarly established from a shelf 2/shelf 1 plot.

Interpretation

These relative yield values include not only the effects of the geometric differences of the shelves so compared, but also the effects due to differences in the beta spectra involved. Thus they are characteristic, for each emitter, of the *mean effective beta energy* of that emitter as sensed by this particular counting arrangement. For spectra of similar shape, such as those represented here, these relative counting geometries may also be considered characteristic of the *maximum* beta energies. Thus, the curves obtained here may be taken as representative of all emitters having beta spectra of the "allowed" shape.

For emitters having spectra of other then the "allowed" shape, or for the composite spectra of mother-daughter or mixed isotopes, the mean effective beta energy is similarly exhibited in the relative counting geometries observed at the different shelf positions. It is convenient to express this mean effective energy arbitrarily in terms of the "equivalent maximum energy" required of an emitter having the allowed spectrum to yield the same relative counting geometry value. Thus, a sample of uncertain beta spectral distribution need only be counted, under standard conditions, at two different shelf positions. By reference to Fig. 2, it can be characterized in terms of its "equivalent maximum energy" (EME). The relative counting geometries corresponding to this EME can now be applied to correlate counts taken at different geometries on related similar samples. Moreover, this EME characterization also affords a convenient tool for investigating the separation of mixed emitters and for evaluating the separation efficiencies of extraction procedures.

The extent of the beta spectral-distribution effects upon the observed relative counting geometries is easily demonstrated. The physical geometries for a 0.675-in. diameter circular spread source were calculated for the different shelf positions, using data derived from those of Cook, Duncan and Hewitt (*25*). These values, which appear to be consistent with more recently published methods (*26, 27*),

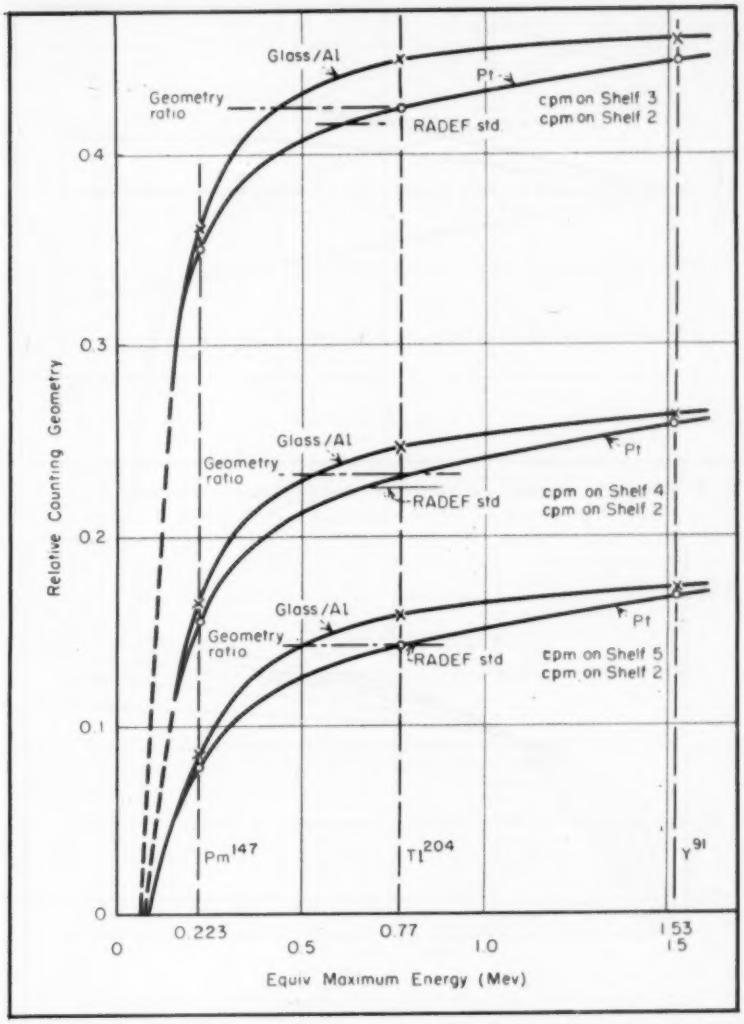

FIG. 2. Relative counting geometries for uncovered beta sources mounted on platinum and on glass-over-aluminum

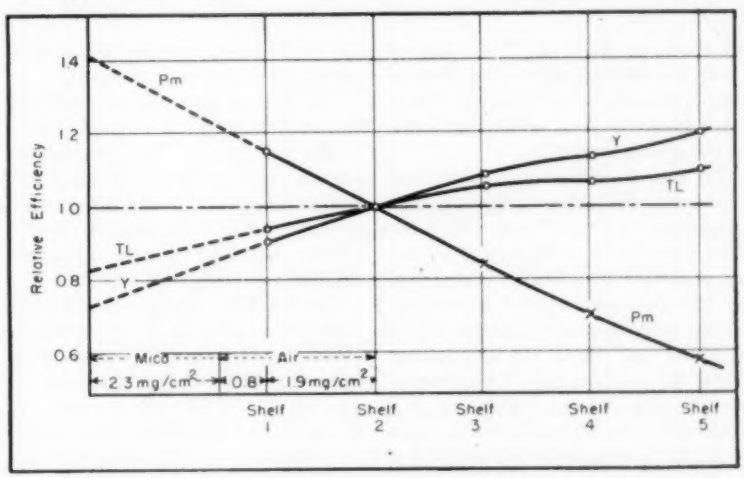

FIG. 3. Relative efficiency, normalized to shelf 2 for sources mounted on glass-over-aluminum

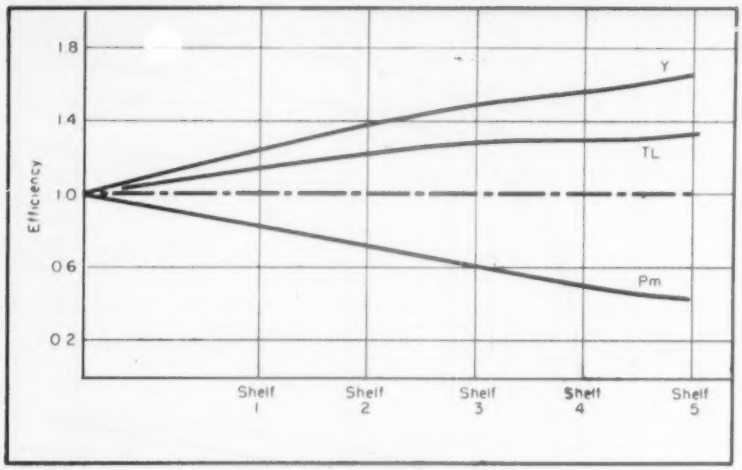

FIG. 4. "Absolute" efficiency for sources mounted on glass-over-aluminum

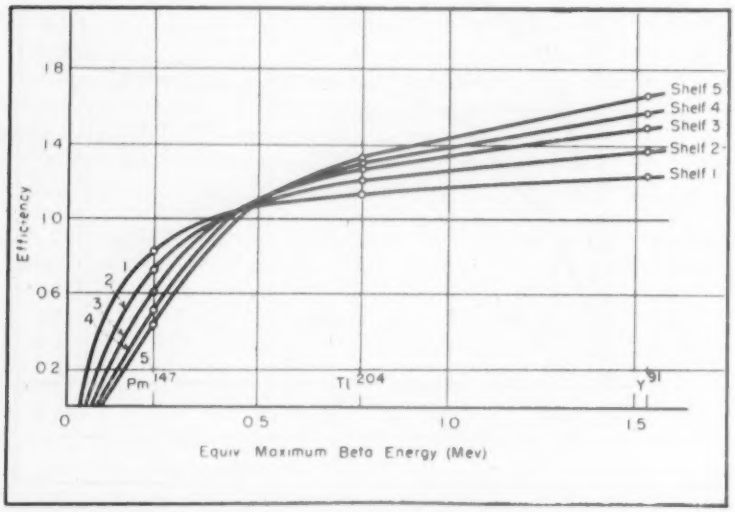

FIG. 5. Efficiency vs energy for sources mounted on glass-over-aluminum

are shown in Table 2. The ratios of these geometries, relative to that of shelf 2, are indicative of relative counting geometries if no scattering or absorption were involved.

For sources mounted on glass-over-aluminum, the ratio of the physical geometries for two different shelf positions corresponds to the relative counting geometry that would be obtained, for the same shelves, for an emitter having an equivalent maximum energy of about 0.5 Mev. At any higher EME the relative counting geometry exceeds the corresponding physical geometry ratio, indicating that in such a case the increased air absorption loss for the lower shelf position is more than offset by the increased scattering from the shelf support walls. At a lower energy the situation is reversed.

For sources mounted on platinum, this equilibrium point comes at a higher EME (0.8 Mev.). This is expected, since a larger number of backscattered low-energy electrons are considerably affected by air absorption, and a greater scattering gain is required to achieve a balance.

The RaDEF standard is not easily compared with the energy reference standards, not only because of its inherently different beta spectrum, but also because of its being covered with 9 mg/cm² of cellophane tape needed to absorb the RaF alpha particles. This difference is exhibited in the fact that its EME, as referred to the curve for uncovered sources mounted on platinum, varies with shelf position, being 0.62 Mev for the shelf 3/shelf 2 ratio; 0.70 Mev for the shelf 4/shelf 2 ratio; and 0.81 Mev for the shelf 5/shelf 2 ratio. If these energies are considered as corresponding to the positions midway between the two shelves involved, that is, the "shelf 2½," "shelf 3," and "shelf 3½" levels, respectively, the shelf 2 EME for the covered RaDEF standard is found to be within the range 0.53 to 0.57 Mev. This demonstrates the fallacy of taking such a RaDEF source as a 1.17-Mev standard.

Absolute Beta Counting

From the experimental data on hand, an effort has been made to deduce further fundamental relationships and to derive a means of approximate absolute beta counting. Although the extrapolation by which the latter evaluation is derived is somewhat tenuous, the disintegration rates so obtained for a number of sources have been fairly well corroborated.

The first step in this calculation was to free the experimental data of the strictly geometric factors. This was accomplished by dividing the observed relative counting geometry values by the corresponding physical geometry ratios. The data so obtained, representing the ratios of the *efficiencies* involved, are given for glass-over-aluminum mountings of each isotope (Fig. 3). As was shown in Fig. 2, for spectra of greater than about 0.5 Mev maximum energy the efficiency increases with distance from the counter tube, and for lower-energy spectra the efficiency decreases with distance. The concavity upwards at the extreme distant position (shelf 5) is attributed to scattering from the floor of the shield assembly.

Scattering from the aluminum sides of the shelf support assembly appears to decrease almost linearly, as the wall area decreases, from shelf 3 to shelf 1, since the other major variable, air absorption, must necessarily decrease linearly with the air path. The scattering effect, except for self-scattering, might be expected to reduce to zero at zero *distance*, while absorption loss should extrapolate to zero at zero *absorber*. Since the data do not separate the two effects, and since self-scattering must be considered present, an extrapolation to zero absorber, in

terms of equivalent air-path distance, was considered most valid (Fig. 3).

If we assume unit efficiency for the intercept at zero absorber, and if we normalize the relative efficiencies for each emitter to the intercept value, we obtain values for the "absolute" efficiencies of the counter to the different samples (Fig. 4). These data are also plotted for the different shelves as a function of maximum beta energy (Fig. 5), and from this latter plot interpolated values for the efficiency have been obtained.

Similar data were derived for sources mounted on platinum. The product of these efficiencies and the calculated geometries of the shelves has yielded values for the over-all counting geometries of each shelf over the entire energy range involved. These derived data are plotted in Figs. 6 and 7.

To test the accuracy of these absolute counting geometry values, a Tl^{204} sample from a solution of known activity was counted. This solution had been evaluated on a coincidence-calibrated counter at Oak Ridge, and the activity expressed to a precision of $\pm 5\%$. The counting rate obtained on glass-over-aluminum indicated a second-shelf counting geometry to Tl^{204} of $9.0 \pm 0.5\%$, as compared to 8.1% as determined from Fig. 6.

A second comparison was made using the data obtained for the RaDEF standard. Extrapolation of the shelf-ratio data for that source indicates a shelf-2 equivalent maximum energy of about 0.55 Mev, and from Fig. 6 the corresponding counting geometry for an *uncovered* source on platinum is found to be 8.3%. The 9 mg/cm² covering has been found to reduce the counting rate by 3% for RaDEF on Ag-Pd, and if we assume this reduction to be roughly proportional to the amount of backscattered radiation, a loss of 3.5% seems reasonable for RaDEF on Pt (*5*). Thus, the covered RaDEF standard would be expected to yield about 0.965 of 8.3% counting geometry, or 7.9%. This compares well with the observed counting geometry of $7.5 \pm 0.4\%$ based on the NBS activity calibration.

More recently, a NBS P^{32} sample was counted on these G-M instruments. Two pairs of samples were counted on two instruments each. The relative counting geometry for shelves 3 and 2, for the samples mounted on glass-over-aluminum, was

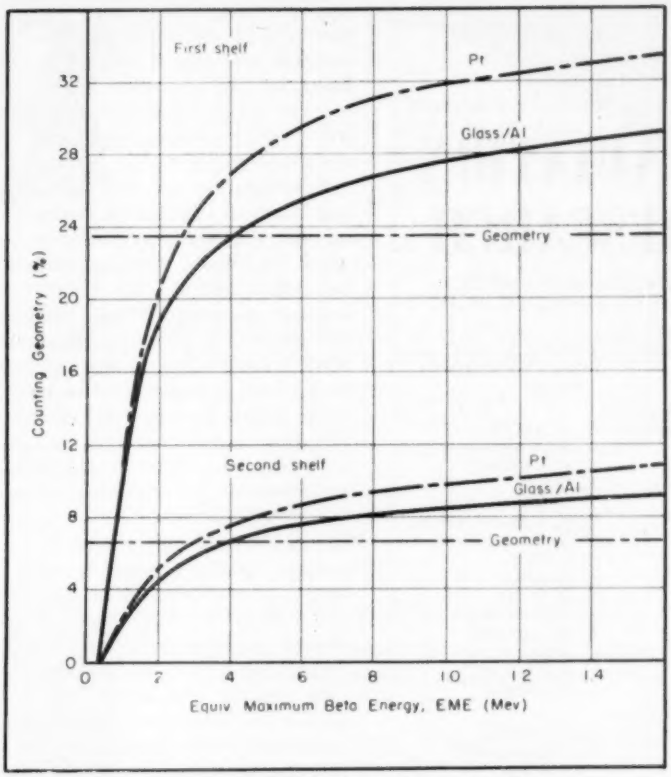

FIG. 6. Counting geometry vs EME for first and second shelf

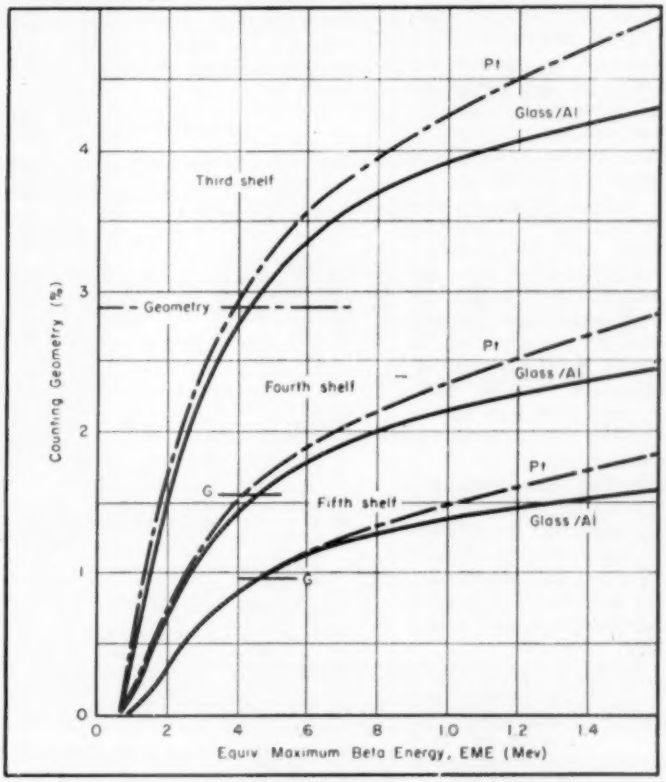

FIG. 7. Counting geometry vs EME for third, fourth and fifth shelf

found to be 0.448, corresponding to an equivalent maximum energy of 0.70 Mev (Fig. 2), for which the indicated counting geometry is 8.0% (Fig. 6). From the NBS evaluation of the solution and the shelf-2 net counting rate, the "true" counting geometry was found to be 8.1 ± 0.1%.

Unfortunately, no such agreement was found in the case of similar P^{32} samples mounted on platinum, for which the "true" counting geometry was calculated at 12.1 ± 0.4%. A counting geometry of only 10.0% is indicated in Fig. 6 for an EME of 1.10 Mev, corresponding to the observed shelf 3/shelf 2 relative counting geometry of 0.438. This may be considered an extreme case, however, as the back-scattering from platinum for such a high-energy source accounts for almost half the total electrons emitted, and the large amounts of salts present in these samples could be expected to result in severe self-scattering and self-absorption. Thus, the EME based on the relative counting geometry does not always represent a true "equivalence" to the counter, and some care must be used in the application of these data.

However, even though the error in this case amounts to −17%, a much greater error would have resulted from the application of either the RaDEF counting geometry (7.50%) or the physical geometry (6.74%).

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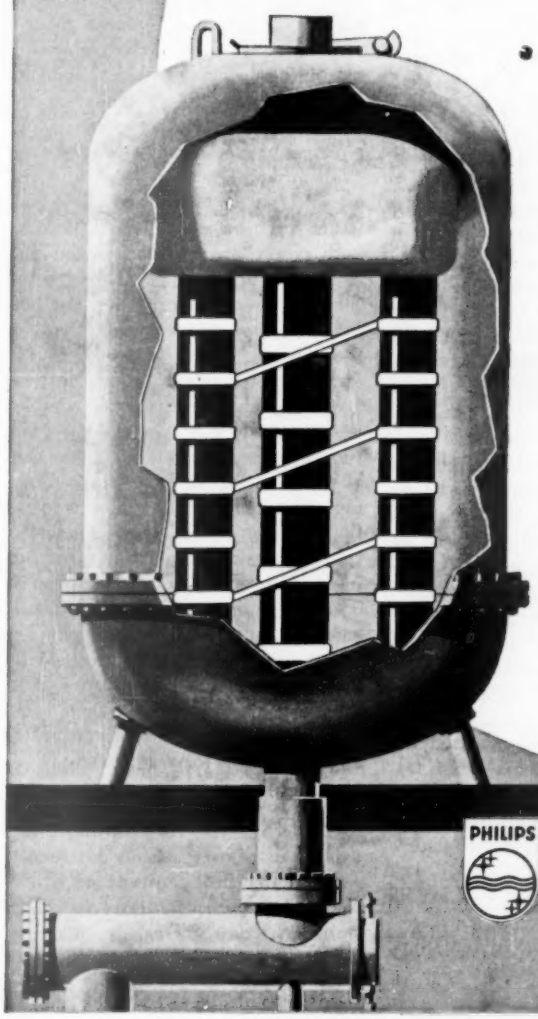

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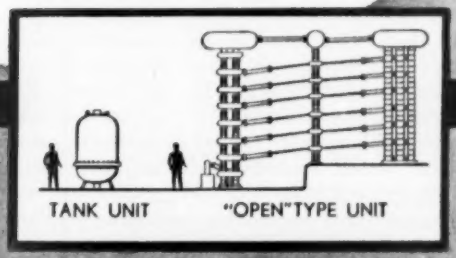

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"—Development of Economic Nuclear Power"

(Continued from p. 9)

sponsoring and financing will fall far short of what is needed unless there are enlisted in this cause the cost-cutting drives, the know-how, skills and competition of many segments of America's business and industry.

And in this connection I am convinced that the time has come to end the monopoly of power reactor information now shared between the Government and a few industrial concerns in order to permit much wider participation under appropriate security controls. I can assure you that the advantaging of private industry, as such, had no part in the forming of the Commission's proposal for industrial participation. Rather we are convinced that getting industry into the atomic energy program, on a privately financed basis, is essential to the attainment of our new urgent national goal —development of economic nuclear power.

It needs to be said also that our proposed policy, calling for both Government and private efforts in the nuclear power field, is an interim policy. As privately financed efforts gain momentum, the work should gradually be transferred from the Federal Government so that eventually industry will be carrying the greater part of the burden of this industrial development.

There is an analogy here to the so-called policy of "candor," that we have been hearing so much about. As I understand it, disclosure of more information about our atomic weapons situation, in relationship to that of the USSR, is considered by some to be essential to an effective working of the democratic process. So, also a disclosure of reactor technology, under appropriate security control, is essential to early development of nuclear power. To those who say that our Commission's contracting policy has resulted in sufficient industrial participation, I would point out that government contracts with industry can seldom simulate normal business—and especially not under conditions of no-risk, cost-plus-a-fixed-fee contracting.

But a word of caution is in order. There has been an illusion, and it is growing, that the present government statutory monopoly is the only substantial block in the road to competitive nuclear power. Any expectation that simply changing the law will solve technological problems is a very grave mistake. Don't underestimate the immensity of the research and engineering job still to be done! Its very difficulty is one of the reasons why your Commission is calling on privately financed industry for help.

I don't think it is generally understood that the basic problem to the question of industrial participation is the need for secrecy. Were it not for a proper concern that the USSR would capitalize for war on our reactor ideas and technology, all reactor data could be immediately published—for all in the free world to work on. Under such conditions, I doubt that there would now be too much objection to changing the Act to permit, under Federal regulation, private ownership of fissionable material and reactors. I doubt that anyone would be heard to say "keep this data in government hands as a government trade secret" because it was developed at great public expense. I think that, only because of the secrecy problem, is there any color at all to the claim that atomic energy technology, having been developed by the government, should be exploited only by the government for the benefit of all the taxpayers. However, this seems to me to be making of secrecy a double strait jacket. Secrecy is a necessary nuisance. It does slow down the work of the Commission. It costs immense sums. But let's not compound its restrictiveness by making it the basis of what is really a political preference for public ownership of the nuclear industry. To my mind such limiting would be like the Soviets insisting on political orthodoxy for work in some areas of science. Let's leave, as far as we can, such strait jacketing to our opponents and not tie up our technological progress with political ideology. Relying on government laboratories and a few government contractors to reach our urgent national goal would be as shortsighted as was France's prewar reliance on government-owned arsenals and nationalized airplane factories for its defense program.

And so another point of the Commission's power policy states:

"It is the conviction of the Commission that progress toward economic nuclear power can be further advanced through participation in development program by qualified and interested groups outside the Commission."

As a postscript to this part of your Commission's power policy I would add one thought. We must be careful to avoid what might be called power myopia—the popular current assumption that peacetime atomic energy means only nuclear electric power. Remember how often, in the past, we have been smothered by the obvious. Even now we may be looking right at some uses for atomic energy of tremendous significance and not seeing them. I know of no better way of "missing the boat" on these as yet unknown uses of atomic energy than to have government administrators or cost plus contractors alone trying to dream them up.

Let me very briefly touch on the background for another point in our policy, which soft pedals the so-called dual purpose reactor. I am sure you are all familiar with proposals to construct reactors which could produce both power and premium-priced plutonium. For this type, it is expected that the premium price for the plutonium would bear any excess cost of the power. When proposed in the early days, before our present weapons producing plutonium reactor complex was initiated, it was a realistic idea. But today we are organized to take care of present weapons demand for plutonium from reactors either now in operation or nearing completion. Therefore, the Commission decided that it was not justified in encouraging dual purpose design reactors unless, in the future, new and long range requirements for additional plutonium are specified by the military. And so, it was felt that, for the present, the policy should discount the Commission's interest in this approach in the following language:

"It is the objective of this policy to further the development of nuclear plants which are economically independent of Government commitments to purchase weapons-grade plutonium."

The next point in our policy treats with another phase of the over-all problem—it states:

"We view the next few years as a period of development looking

toward the realization of practical nuclear power. On this basis we conclude that the time is not yet at hand for the report called for in Section 7(b) of the Atomic Energy Act of 1946."

Some of the proponents of continued government monopoly argue that Congress, by Section 7(b), intended to preclude any legislative moves to permit private activity in atomic energy until the day of practical nuclear power had arrived. You will recall that that day was to be when the Commission reached the conclusion that "any industrial or commercial or other non-military use of fissionable material or atomic energy had been sufficiently developed to be of practical value."

It should be fairly obvious that the industrial and peacetime aspects of atomic energy are in no sense as revolutionary as was feared back in 1946 when Section 7(b) was drawn. I suspect that in the debates ahead the present day opponents of liberalizing legislation will fall back on less legalistic argumentation than this 7(b) objection. In any event, the Joint Committee on Atomic Energy has asked your Commission to prepare a preliminary 7(b) report. It strikes me that with the filing of such a report, which will necessarily be a preliminary one, that any possible Section 7(b) bearing on the present stage of nuclear power development will cease.

In conclusion, I see the United States nuclear power policy calling now, in the year 1953, for early development of practical power reactors. We must have flexibility if the development is to go as quickly as the international situation demands and the technological situation warrants. This means attacking the problem on a broad front, extending from our weapons material producing reactors at one extreme, thru military propulsion reactors, thru government financed full-scale power producing units, all the way to privately financed research, development and ultimately private construction of full-scale units. It will require a liberalization of the statute and perhaps a more liberal policy of declassification of restricted data. Just as I hope Congress will not prevent the opening of the legal doors to the dollar inspired energy, brains, resources, and techniques of private enterprise, so I hope that fiscal considerations will not prevent continuance of vigorous interim government development and construction programs. END

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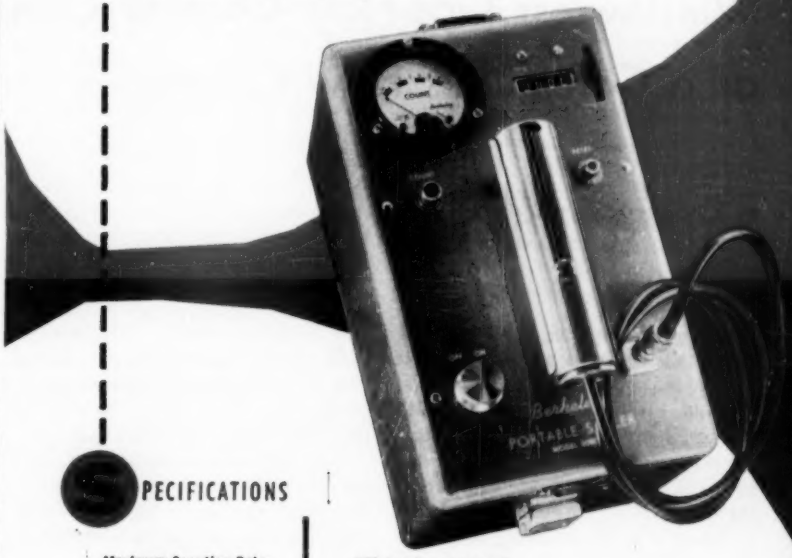

SPECIFICATIONS

Maximum Counting Rate:	100 counts per second.
Paired Pulse Resolution:	100 seconds.
Input Sensitivity:	½ volt.
Interpolation Indicator:	Scale-of-eight meter.
Register:	4-digit resettable.
High Voltage Supply:	900 volts.
Batteries Used:	6 - 1½ volt; 1 - 45 volt.
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M-21

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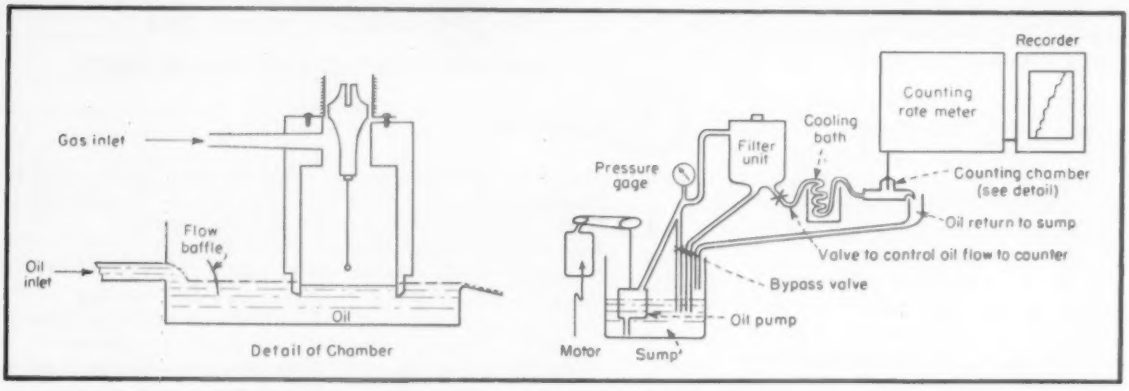


FIG. 1. Counter and oil circulating-filtering arrangement

Windowless Gas-Flow Counter Operated as a Continuous Flow Counter

By A. H. EMMONS* and J. A. NORTON†

A manufacturer of paper oil-filter elements uses a formaldehyde-based resin to impart strength to the filtering medium. It was desired to evaluate the loss, if any, of this resin under various service conditions. The resin was prepared from formaldehyde-C^{14} and the C^{14} activity levels were measured in the oil with the counting technique described here.

Synthesis of the resin was achieved with a specific activity of 2.65 μc of C^{14} per gram of resin. Owing to the capacity of the test apparatus, 2 kg of oil were required for a satisfactory test. It was necessary that a small loss of resin should be detectable in the oil, that is, 0.8 gm of resin or 2.12 μc C^{14} in 2,000 gm of oil. This then required the detection of 1×10^{-3} μc C^{14} in 1 gm of oil, which could not be achieved by ordinary techniques (i.e., infinite thickness oil layer beneath a thin-window G-M tube). Further, it was desired that the resin concentration in the oil be measured continuously rather than by multiple sampling techniques.

The problem was solved by using a gas-flow counter as a semi-dip counter. The counting chamber from a gas-flow counter‡ was placed in the oil system as shown in Fig. 1. The counting gas§ was bubbled out from under the lip of the counting chamber, which was positioned so that the oil surface sealed the chamber.

Output of a ratemeter¶ connected to the chamber was fed to a recording d-c milliammeter.‖ The apparatus was standardized by adding 1-gm aliquots of the tagged resin to the circulating oil. The calibration curve is shown in Fig. 2.

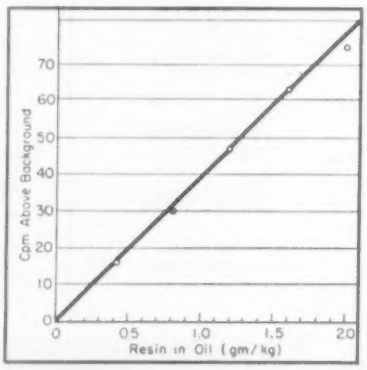


FIG. 2. Calibration curve

This apparatus operated very satisfactorily over the period encompassed by these tests. It is felt that a similar arrangement would lend itself to other problems involving detection of weak beta emitters in low-vapor-pressure hydrocarbon liquids, such as an evaluation of the wear properties of plastic gears prepared from C^{14}-labeled resins.

* Radiological Safety Department, University of Michigan, Ann Arbor, Mich.
† AC Spark Plug Division, General Motors Corp., Detroit, Mich.

‡ Model 200, Research Equipment and Service, Chicago, Ill.
§ Q-gas, Nuclear Instrument and Chemical Corp., Chicago, Ill.
¶ Model SC-34, Tracerlab, Inc., Boston, Mass.
‖ Model AW, Esterline-Angus.

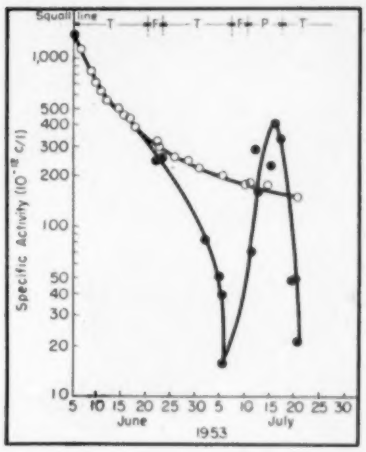
On the Artificial Radioactivity of Rainfall

By P. E. DAMON and P. K. KURODA
Department of Chemistry, University of Arkansas
Fayetteville, Arkansas

On the night of June 5, 1953, during the course of research on the natural radioactivity of the atmosphere (*1*), rainwater samples were collected that contained an intense source of beta radiation after the decay of RaB + C and ThB. The decay of this activity (see illustration) was characteristic of fission products. Chemical separations and radiochemical analysis have resulted in the identification of Sr^{89} and $Ba^{140} + La^{140}$, etc. (Table 1). Analysis of the fission-product activity of rainwater, from all storms during the period June 5 to July 23, has resulted in an apparent correlation between the artificial radioactivity and the origin of the prevailing air mass.

Except for the brief intrusion of a stationary front from June 20–23, a tropical marine air mass prevailed during the month of June until July 7. The artificial radioactivity of the rain water rapidly decreased during this time, and it appeared that the air mass was being purged of its content of fission products resulting from the nuclear bomb tests. On July 7, a polar continental air mass invaded this region and rapidly extended itself to the Gulf of Mexico. Artificial radioactivity was unusually high during this entire period. However, upon the return of the tropical marine air mass, the activity again fell to values consistent with previous values before the intrusion of the polar continental air mass. Analysis of the decay curves indicates that the age of the activity falling from the two air masses is not significantly different.

The artificial radioactivity of rainwater, although less than that of the short-lived natural radioactivity, was considerably greater than the long-lived natural radioactivity (Table 2). It was possible to separate and count the artificially produced isotopes in lake water (Table 1). The total fission activity falling in the vicinity of Fayetteville during this two-month period is in excess of 10^{-8} curie per square meter. It should be possible to determine the age of natural waters by analysis of the relative content of the different isotopes resulting from fission.



ARTIFICIAL ACTIVITY of rainfall at Fayetteville, Ark. T is tropical air mass; P, polar air mass; F, front within region. Open circle is residual activity of June 5 rainwater evaporate; solid circle, fission-product activity of rain

* * *

This work was supported in part by the U. S. Atomic Energy Commission.

TABLE 1—Radiochemical Analysis of Rainwater (7/2) and Lake Fayetteville Water

Chemical fraction	*Significant isotopes expected*	*Rainwater* *Beta activity* (10^{-12}c/l)	*Rainwater* *Apparent half-life*	*Lake water* *Beta activity* (10^{-12}c/l)
Evaporate	all nonvolatile	75	23.5d	8.7
Barium	Ba^{140}	2.5	12.5d (decay) 40 hr gr.	1.0 (max.)
	Ra	2.4	3d growth	
Strontium	$Sr^{89} + Sr^{90}$	13.7	50d	1.6
Iron	Ce^{141}, Ce^{143}, Pr^{143}, Nd^{147}, Y^{91}, Zr^{95}, Cb^{95}	28.0	17d	1.0
Nitric insoluble	soils and silicates	10.5	21.5d	0.4
Lead	Pb^{210}, Bi^{210}, Ru^{103}	3.3	22d	0.3
Not recovered		15		4.4
Evaporate control	Contamination of	<0.5		
Barium "	chemicals, glass-	<0.02		
Strontium "	ware, etc.	<0.2		
Iron "		<0.2		
Lead "		<0.05		

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1. P. E. Damon, P. K. Kuroda. Paper at annual meeting of American Geophysical Union, Washington, D. C. (May, 1953)
2. J. H. Blifford, L. B. Lockhart, Jr., H. B. Rosenstock, Naval Research Laboratory Report 4036 (1952)
3. W. F. Libby, private communication

TABLE 2—Radioisotopes in Rainwater

Radio-isotope	*Specific acticity* (c/l)	*Investigator*
Rn	$<10^{-11}$	Authors
RaB + C	10^{-9}–10^{-7}	Authors
RaD	10^{-13}–10^{-12}	Authors and ref. *2*
Ra	10^{-12}	Authors (only one determination)
ThB	10^{-12}–10^{-10}	Authors
Tritium	10^{-11}–10^{-12}	Libby (*3*)
Fission products	10^{-11}–10^{-9}	Authors, June 5 to July 23, 1953

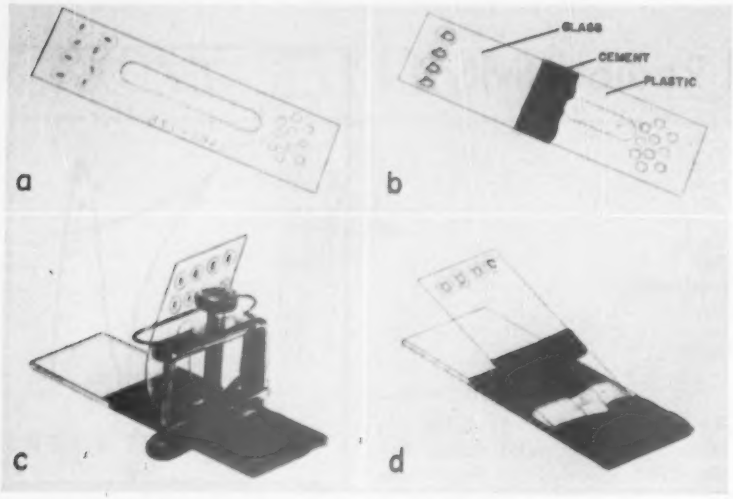

FIG. 1. (a) Flexible coverslip with sections mounted. (b) Shortened flexible coverslip, with specimens that require staining with solutions that can soften plastic coverslip mounted on attached glass coverslip. (c) Clamp and wire retainer hold coverslip away from nuclear track plate for processing. (d) Finished autoradiograph with attached coverslip

A Versatile Method of Micro-Autoradiography

By FRANK E. HOECKER, PAUL N. WILKINSON, and JACK E. KELLISON
Radioactive Isotopes Research Laboratory
University of Kansas, Lawrence, Kansas

An autoradiographic method in use in our laboratories for more than four years has undergone refinements dictated by actual experience. The unique feature of this technique is the continuity of precise registry between the microscopic structure of the specimen and the radioactive substance embodied by it, on the one hand, and the tracks of the emitted particles in the emulsion on the other hand, throughout any procedure that necessitates the separation of the specimen from the autoradiograph. Following the exposure of the photographic emulsion to the radiation from the specimen, the specimen section, which may be soft tissue, bone, or mineral, may be removed from the emulsion for any purpose as many times as desired, and replaced at will in exact registry.

The unusual simplicity of this method lies in the fact that it utilizes commercially available nuclear track plates and that only one special procedure, that of cementing a coverslip to the nuclear track plate, is involved. It is inherently free of photo-chemical artifacts because the specimen sections are in contact only with dry emulsion. The method may be used for any material that can be sectioned; staining solutions do not come into contact with the emulsion, and processing solutions never contact the specimen. It may be used for autoradiography of any particles to which the emulsion is sensitive; the duration of exposure may be accurately controlled for quantitative work, and the exposure of any specimen may be repeated as often as desired. This method avoids all manipulations that might result in displacement of the radioactive substance in the specimen, and those that might produce distortion or displacement of the emulsion with respect to the microscopic source. Particle tracks in the emulsion are all in focus in the same plane.

It is believed that no other single method embodies all these advantages.

Specimen Preparation

The specimen or section of any material containing radioactive substance may be prepared by any method applicable to that material. It is assumed that the material to be examined will be either microscopically transparent sections or opaque sections not more than a millimeter in thickness.

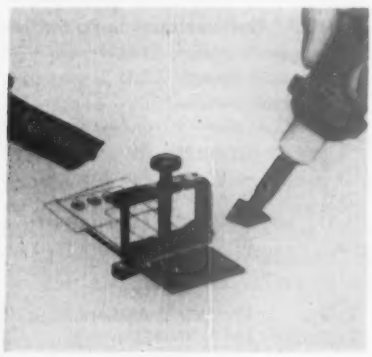

FIG. 2. Small commercially available soldering iron with specially made tip is used in cementing process

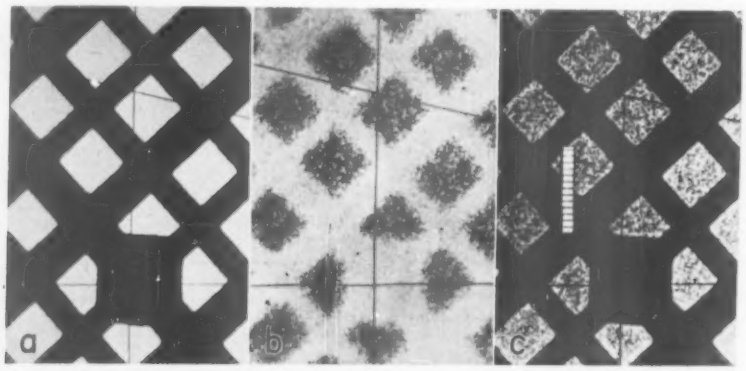

FIG. 3. (a) Photomicrograph of thin copper, electron-microscopy specimen screen. Open spaces about 80 microns square. (b) Photomicrograph of alpha-particle track pattern on autoradiograph of specimen screen. (c) Composite print of a and b

For most purposes, the prepared section of the specimen is mounted on a flexible plastic coverslip. This procedure involves only the substitution of the flexible coverslip* in place of the customary glass microscope slide. These coverslips have essentially the same width and length as the glass slides, but have a thickness of only 0.25 mm. Any mounting medium may be used, although those that tend to soften the coverslip surface require special care to avoid roughening the coverslip surface and introducing air bubbles between the section and the coverslip.

Great care must be exercised to prevent the upper surface of the specimen being contaminated.

Sections of tissue or other material that require staining involving the use of solvents that soften the plastic coverslip can be easily handled by first mounting them on a rectangular glass coverslip that is then cemented to the plastic coverslip. The preferred procedure is to shorten the plastic coverslip by cutting off a piece about ¼-inch shorter than the glass coverslip. The glass and plastic are then cemented together in the overlapping ¼ inch so as to produce a single composite coverslip having a length equal to that of the original plastic. The cement used here is the same as that used later to cement the coverslip to the nuclear track plate.

Since removal of the section from the autoradiograph is accomplished by bending the flexible coverslip, and since bending in the region of the mounted sections must be avoided, the coverslip must be weakened over about one-third its length to concentrate bending in the center portion. This is accomplished by punching out of the center portion a rectangular piece of the plastic about ¾-inch long and 5/16-inch wide. This must be accomplished without distorting the coverslip or introducing cracks in the plastic on either side of the cut-out region.

Finished mountings of both types are shown in Fig. 1.

Attachment to Plate

Continuity of registry between the autoradiographic track pattern and the radioactive particle source in the section depends upon firm and unyielding attachment of the coverslip to the emulsion surface of the nuclear track plate. The end of the coverslip opposite that on which the sections are

* Flexible coverslips are obtainable from Charles F. Hubbs, 389 Lafayette Street, New York, New York.

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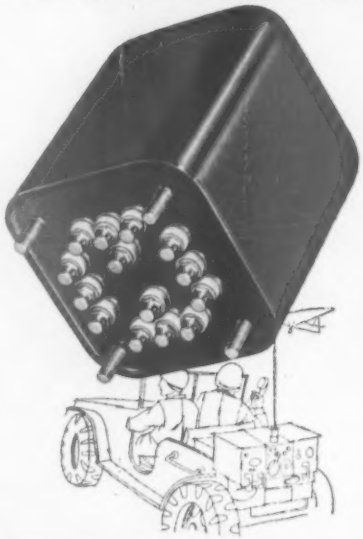

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PMS-150	MS-90028	325-0-325	150	245	6.3	5	5	3	7¼
PMS-175	MS-90029	400-0-400	175	318	5	3	6.3	8	10
PMS-250	MS-90030	450-0-450	250	345	5	3	6.3	8	13
PMS-350	MS-90031	350-0-350	250	255					7½
PMS-550	MS-90032	550-0-550	250	419					11
PMS-800	MS-90036	800-0-800	250	640					16½

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FMS-53	MS-90018	5.0	3.0	2500	1¾
FMS-510	MS-90019	5.0	10	2500	4
FMS-62	MS-90020	6.3	2.0	2500	1¾
FMS-65	MS-90021	6.3	5.0	2500	2¾
FMS-610	MS-90022	6.3 CT	10	2500	5
FMS-620	MS-90023	6.3	20	2500	8
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mounted is cemented to the emulsion surface of the nuclear track plate, using a one-to-one mixture of beeswax and rosin. The firmness of the cemented joint is improved by first punching six or eight holes 1/8-inch in diameter in the end of the coverslip.

A drop or two of cement is melted onto the emulsion surface of the plate by holding the wax in contact with the hot tip of a small electric soldering iron.* The performance of the soldering iron is improved by attaching to it a specially designed tip that is screwed to the heating element unit on threads provided in manufacture. This iron, shown with the tip in place in Fig. 2, is used to smooth out the thin layer of cement on the surface of the emulsion.

While this cement is still hot, the coverslip is positioned on the plate with the sections separated from the emulsion surface by a thin piece of absorber, and clamped in position by means of a Hoffman tubing clamp (Fig. 2). Eight to ten more drops of cement are melted onto the upper surface of the coverslip over the area to which cement has already been applied. This additional cement is then melted and smoothed into and over the holes in the end of the coverslip, using the diagonal face of the electric soldering iron. The cement melted into the holes unites with the cement below the coverslip and acts as cement rivets. The clamp is removed as soon as the cement is cool.

Exposure Control

One important feature of this technique is that the time of exposure of the nuclear emulsion may be precisely controlled. This is of considerable importance if the amount of radioactive substance is to be evaluated by means of calibrated densitometric measurements or by means of track counting.

This exposure control is easily obtained by interposing an absorber between the emulsion and the sections when the coverslip is placed on the nuclear track plate. The thickness of absorber will be determined by the material used and by the type and energy of the particles emitted. Exposure may be started at any desired time by removing the absorber, and stopped either by returning it or by lifting the coverslip away from the emulsion.

During exposure the sections are held firmly in contact with the emulsion by placing a 200-gm lead cube on top of the coverslip above the sections. Ex-

* Unger Electric Tools, Inc., Los Angeles, California. 22.5 watts.

posure should be carried out in a light-tight box at 68° F and at a relative humidity of 50% or less.

Processing

During processing, the sections are removed from the emulsion by lifting the end of the coverslip. This lifted end may be held vertical to the nuclear plate by replacing the clamp originally used to hold the coverslip in position during cementing. The two vertical portions of a piece of wire bent as shown in Fig. 1 are inserted into holes in the upper yoke of the clamp. The lifted end of the coverslip is inserted through the loop of this wire and is held in this position throughout processing.

The sections are thus never in contact with the processing solutions or wet emulsion. They may, however, be precisely returned to the position occupied during exposure at any time simply by releasing the lifted end of the coverslip and allowing it to return to its exposure position. There is one prerequisite to exact registry: examination of the section and autoradiograph must be carried out at the temperature of exposure to avoid effects due to the differential coefficient of expansion between plastic and glass.

Processing of the exposed plates may be carried out in accord with recommendations of the manufacturer or as dictated by special effects desired. Small numbers of autoradiographs are carried through in trays, but large numbers may advantageously be handled in a special processing tank (*1*).

Staining

Staining of sections may be carried out any time after exposure and processing are completed without having the autoradiographs affected in any manner. Since exposure precedes staining, the effects of leaching and displacement of radioactive material are completely avoided. Staining solutions and solvents cannot come into contact with the emulsion, and hence discoloration of the emulsion is avoided. Staining should, however, be delayed until it is determined that the time of exposure is correct for the purpose in mind. If the exposure is to be repeated, this should be done before the section is stained.

Exposure of the same mounted specimen may be repeated as many times as desired merely by heating the cement (an advantage of the beeswax-rosin mixture), removing the coverslip and cementing it to another nuclear track plate. A completed autoradiograph

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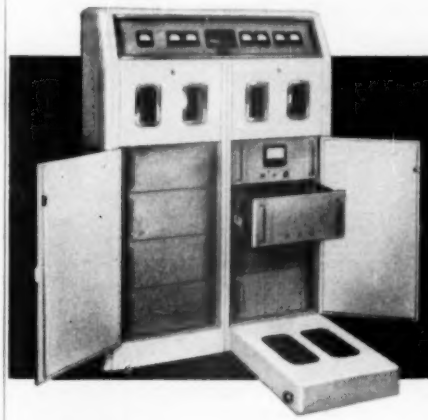

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with sections mounted on a composite (glass cemented to plastic) coverslip is shown in Fig. 1d.

Registry

The precision with which the specimen can be returned to its original position on the emulsion has been tested by examining the registry between a radioactive grid-source mounted on a coverslip, and the resultant alpha-particle pattern on the autoradiograph. The grid-source was made by mounting an electrolytically deposited copper screen, of the type used in electron microscopy, over a small portion of the area of a coverslip on which polonium had been deposited. The autoradiograph was made with the coverslip mounted as described previously. A 20-μ thickness of polystyrene film was interposed between the emulsion and the alpha-particle source during exposure to absorb all alpha-particles whose trajectories made angles less than 75 degrees with the surface.

In Fig. 3 are photomicrographs of the copper grid (a) and of the corresponding alpha-particle track pattern (b) on the autoradiogram. The precision of registry is demonstrated by the composite print of Fig. 3c in which the grid of (a) is printed superimposed on the pattern of (b). The composite print is made from separate photomicrographic negatives made with the coverslip-source lifted away from the autoradiograph. The transverse lines on the prints serve to maintain precision of registry through the photomicrographic manipulations described elsewhere (*2*).

A fair estimate of the precision of registry may be arrived at by reference to the scale superimposed on the composite print (Fig. 3c) in which the divisions each represent 10 microns. The alpha-particle tracks encroach upon the grid shadow areas to essentially the same extent on all sides around the periphery of the exposed areas, and there is no evidence of a shift of the pattern in any direction. It seems safe on the basis of this evidence to say that exact registry is maintained throughout the entire proces to within 1 or 2 microns.

* * *

This article is based on work performed under contract AT(11-1)-83-II for the U. S. Atomic Energy Commission.

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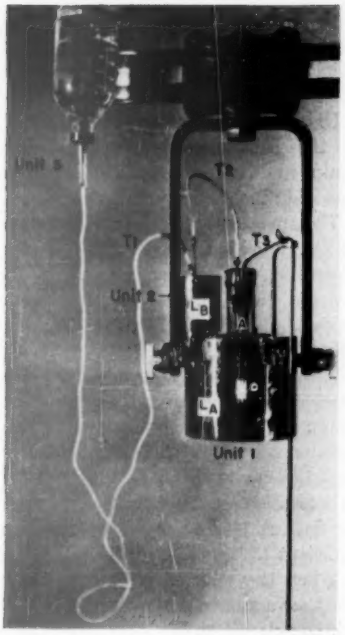

FIG. 1. Complete apparatus for intracavitary administration of colloidal radiogold

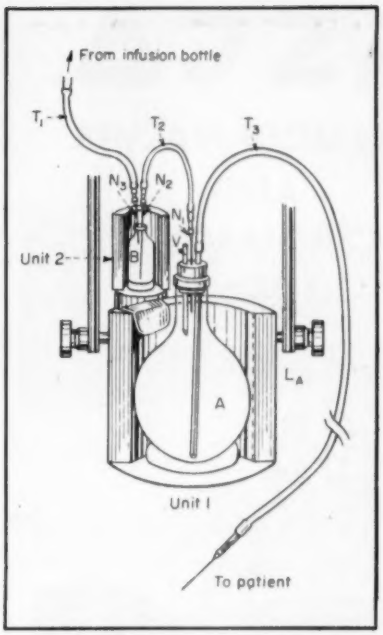

FIG. 2. Units 1 and 2 of intracavitary administration apparatus

Apparatus for Intracavitary Administration of Colloidal Gold

By ROSALYN S. YALOW and BENJAMIN B. COHEN
Radioistope Unit, Veterans Administration Hospital
Bronx, New York

A variety of systems for intracavitary administration of radiogold (Au^{198}) have been reported (*1–6*). The apparatus described here is simpler to handle than those previously described and offers additional safety features for the medical and laboratory personnel as well as for the patient.

The operating principle is the transfer without direct handling of suitably diluted radiogold into the patient by the hydrostatic pressure of a siphon system. The apparatus permits testing for the absence of critical leaks and the patency of the flow system prior to removal of the gold from the shipping container.

The apparatus consists of three basic units shown in Fig. 1 and illustrated in detail in Fig. 2. Unit 1 is a lead support L_A, in which is placed a round-bottomed flask A initially containing 100–200 ml isotonic saline solution. The rubber stopper for this flask contains an air vent V, a 15-gage needle N_1, and a glass tube to which is attached a rubber tube T_3, connected to a needle adapter. The entire unit, except for L_A, is autoclaved with the rubber tubing tightly clamped close to the needle adapter, which is covered with a protective rubber cap.

Unit 2 consists of a lead shield L_B, securely clamped to L_A, into which the rubber-capped bottle B, containing the entire radiogold shipment, is placed with the aid of remote handling tongs. The pressure in the shipping bottle is brought to atmospheric by puncturing the cap with a 26-gage ½-in. needle attached to a 20-ml syringe. Two 15-gage needles, N_2 and N_3, are inserted through the cap after removal of the smaller needle.

Both units are supported in a yoke suspended from a modified portable

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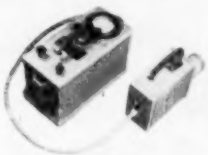
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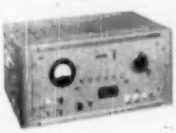
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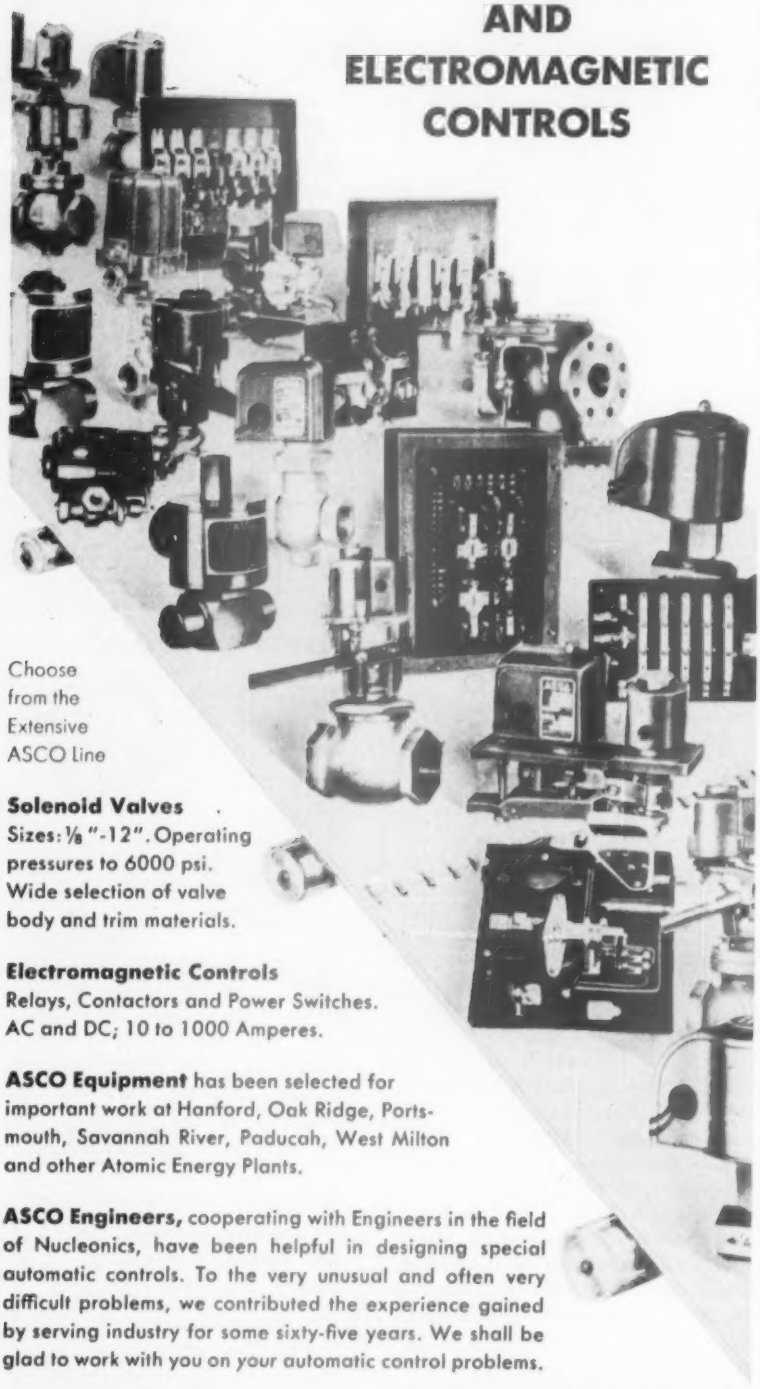

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X-ray mount. The short length of sterile rubber tubing T_2, connecting units 1 and 2, is equipped with needle adapters at both ends.

Unit 3 is a saline infusion bottle, used in the usual inverted fashion and equipped with a standard infusion Venopak, including tube T_1.

The apparatus is assembled as shown in Fig. 1, with tight clamps on tubes T_1 and T_2.

After the body cavity has been tapped, T_3 is connected through an adapter to a side-arm of a 3-way metal stopcock attached to the needle or leakproof cannula used for the tap. The clamp on T_3 is then opened, and saline solution starts to siphon automatically into the cavity from flask A.* The hydrostatic pressure obtained by placing flask A 1–2 ft above the patient is sufficient to insure a free flow.

When the solution is flowing freely and the volume in A is reduced to 25–50 ml, the clamp on T_1 is removed, permitting the saline from the infusion bottle to wash the radiogold from the shipping bottle into A, from which it flows into the patient. In general, an additional 100–300 ml of saline from the infusion bottle is washed through the system into the patient. If the flow is too fast, it can be regulated either by lowering the flask or by adjusting the clamp on T_3.

Radiation Levels

The entire administrative procedure usually requires about 3 minutes, with the bulk of the radioactivity passing into the patient in about half a minute. The residual radioactivity in the entire system, when measured on two occasions, amounted to about 2% of the administered dose. The round bottom of A permits essentially complete emptying. About half of residual radioactivity was found in the fluid remaining in the system, principally in T_3. The other half had apparently adhered to the walls of the containers and the tubing.

The lead shield for flask A contains two vertical, diametrically opposite slits. A flashlight is mounted on the shield to illuminate the openings. It is therefore possible for an observer several feet from the apparatus to see the fluid level in A. The radiation re-

* Siphoning starts automatically when the clamp on T_3 is removed for the following reason: During autoclaving the air in T_3 is replaced by steam. When the system is brought to room temperature and pressure, the steam in T_3 condenses, and saline from A rises in the tube to fill the partial vacuum thus created.

ceived three feet from bottle B, which is shielded with ½-in. lead, is less than 1 mr/hr/100 mc Au^{198}. Thus, during the time of preparation, only negligible radiation is received by any of the participants in the procedure.

The radiation received during the transfer is not readily measurable since the time of transfer is so short. A rough calculation indicates that if the physician were to steady the tapping needle with a 50-ml syringe or a clamp, the dose to his hands would be less than 40 mr/100 mc Au administered. The generalized body radiation received by this physician would be about 7 mr during the procedure. Other assisting personnel would receive considerably less. In fact, with this procedure, the radiation from the treated patient represents the only potential hazard.

The apparatus described has a number of additional noteworthy features:

1. It is readily portable since the lead shields L_A and L_B are supported on the yoke of a modified portable X-ray mount. This mount also can serve as a support for *in vivo* Geiger and scintillation counters.

2. The radiogold is diluted before administration. Therefore, at no time is there more than about 10% of the dose in the tubing leading to the patient. If, for any reason, the infusion into the patient stops, the problem of safe handling in the removal of the radiogold is made more simple. Further, this dilution assures that the dose is not delivered to the patient in such a small volume that local concentrations of radioactivity are produced.

3. If leakage occurs at any junction but the joint of T_3 and the needle leading to the patient, the fluid will leak into a cupped shield. The absence of leakage at this critical joint is checked by the initial infusion of nonradioactive saline solution.

4. Since syringe pressure is not used to force fluids through the system, the danger of blowouts is avoided.

* * *

We are indebted to Paul Newman for the illustrations. Thanks are also due to Florence Cavanagh for secretarial assistance.

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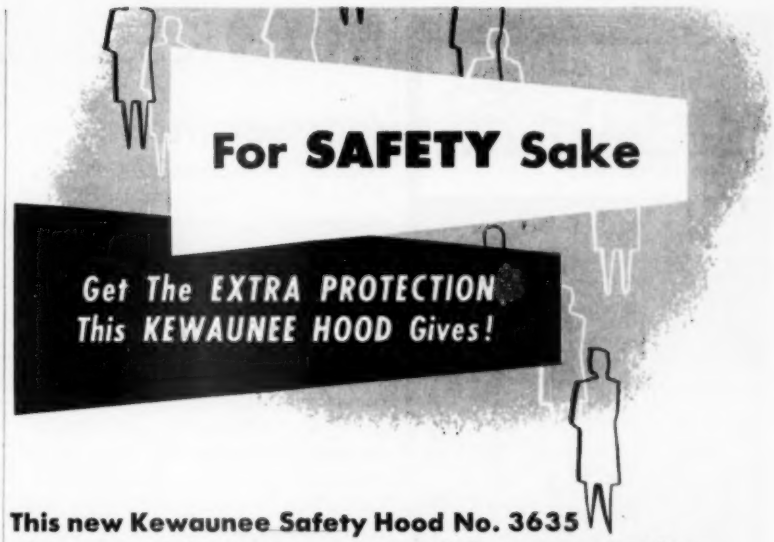

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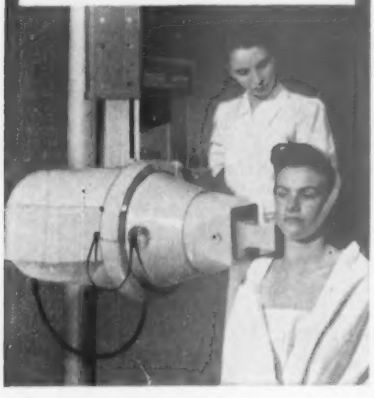

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BOOKS

BOOKS RECEIVED

Methods of Mathematical Physics, Vol. 1, by R. Courant and D. Hilbert, Interscience Publishers, Inc., New York (Interscience Publishers Ltd., London), 1953, xv + 561 pages, $9.50. Translated and revised from the German original, this first volume of the two-volume series represents the authors' attempt to demonstrate the basic relationship existing between the fields of mathematics and physics. Volume 1 is concerned with topics related to the theory of linear transformations and quadratic forms, and treats the application of the calculus of variations to eigenvalue problems.

An Introduction to Relaxation Methods, by F. S. Shaw, Dover Publications, Inc., New York, 1953, 396 pages, $5.50. Different types of equations are emphasized as a guide for solving problems arising in such fields as fluid mechanics, design of electrical networks and machinery, electron-optics, chemistry, and physics.

The Physics of Radiation Therapy, by H. E. Johns, Charles C Thomas, Publisher, Springfield, Ill., 1953, viii + 286 pages, $8.50. *(To be reviewed.)*

Experimental Nuclear Physics, Vol. 2, edited by E. Segrè, John Wiley & Sons, Inc., New York, 1953, viii + 600 pages, $12.00. *(To be reviewed.)*

Design for Decision, by Irwin D. J. Bross, Macmillan Co., New York, 1953, viii + 276 pages, $4.25. In language understandable to the layman, this book discusses statistical decision, the scientific method for making decisions.

ALSO OF NOTE

Use of Isotopes in Plant and Animal Research. This 272-page report, TID-5098, contains the 20 papers presented in June, 1952, at the conference at Kansas State College sponsored by Kansas State College, Argonne National Laboratory, and AEC Isotopes Division. Discussed are the uses of radioisotopes in study of soil fertility, plant-availability of phosphorus, nitrogen fixation, animal metabolism, insects and insecticides, and photosynthesis. Genetical effects of thermal neutron irradiation in plants, use of P^{32} as tracer in research on intact dairy cows, use of C^{14} in plant research and carbohydrate metabolism, and effect of radiations on growth and development of plants are also discussed. *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., $1.25.*

Proceedings, 1953 Conference on Nuclear Engineering. This 606-page illustrated report presents the proceedings of the September, 1953, conference held at Berkeley, California. Topics covered include: power and research reactors; equipment for neutron research; nuclear power-plant economics; kinetics, instrumentation, and control; materials; accelerator engineering; uses of isotopes and nuclear radiations; chemical processing and heat transfer; and radioactive materials handling. *California Book Co., 2310 Telegraph Ave., Berkeley 4, Calif., $7.50.*

Radioisotope Techniques—Vol. I, Medical and Physiological Applications, published by the British Ministry of Supply. This 466-page book contains proceedings of the Isotope Techniques Conference held at Oxford, July, 1951, and sponsored by the Atomic Energy Research Establishment at Harwell, England. Fields covered by the papers are therapy and diagnosis, biochemistry and metabolic studies, and plant biochemistry. *Available from Sales Section, British Information Services, 30 Rockefeller Plaza, New York 20, N. Y., $11.00.*

Standard X-Ray Diffraction Powder Patterns (Circular 539), Vol. I, by H. E. Swanson and E. Tatge, Vol. II, by H. E. Swanson and R. K. Fuyat. Patterns made recently for 84 inorganic substances at the National Bureau of Standards are presented, compared with those found in the ASTM file and in the literature, and recommended for adoption as standard patterns. Patterns were made with a G-M counter spectrometer. For each NBS pattern, the three strongest lines are given. Lattice constants and density are calculated, and, wherever possible, the refractive indices are given. *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., each $0.45.*

Graphs of the Compton Energy-Angle Relationship and the Klein-Nishina Formula from 10 kev to 500 Mev. This 89-page monograph, NBS Circular 542, is a tabulation of the

LETTERS

Factors of Safety

DEAR SIR:

A number of times recently, I have observed disturbing references to factors of safety, in papers or talks on radiation protection, that represent to me a fundamental error in thinking. I am sure we all agree that in the design of shielding or the planning of a procedure, whenever all of the factors affecting the exposure of personnel are not known, appropriate factors of safety should be introduced.

In the case of the determination of the actual exposure of personnel by radiation measurements, such as with personnel monitoring equipment, any so called "factor of safety" to account for a low degree of accuracy in an instrument or film measurement should *not* be used.

There will come a time when exposure histories of large groups of radiation workers will be reviewed to adjust our concept of a Maximum Permissible Exposure. If, at that time, our records show a higher cumulative personnel exposure than actually existed, the so called "factors of safety" applied will turn out to have been "factors of unsafety."

Let us, therefore, record the "best estimate" of personnel exposure, rather than the "highest possible," in order that our records do not betray us.

—HANSON BLATZ
Chief, Radiation Branch
Health and Safety Division
New York Operations Office
U. S. Atomic Energy Commission
New York, New York

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mathematical relationships in graph form, permitting interpolation accurate to 2%. The accuracy of the curves is estimated at 1%, taking as a basis the constants of DuMond and Cohen [*Physical Review* **82**, 555 (1951)]. *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., $0.55.*

Handbook of Noise Measurement. This new handbook replaces the "Noise Primer." Consisting of over 100 pages, it covers the measurement of airborne sounds. including definitions, standards, measuring equipment, procedures, and interpretation of results. *General Radio Co., 275 Massachusetts Ave., Cambridge 39, Mass., $1.00.*

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NEWS

Westinghouse Gets Contract to Build Full-Scale Power Reactor by 1957; Rickover to Supervise Project

The Atomic Energy Commission has confirmed previously published reports (NU, Sept. '53, p. 78) that it has contracted for the building of a full-scale power reactor. The Westinghouse Electric Corp. has been chosen as prime contractor under the supervision of Rear Admiral H. G. Rickover, chief of AEC's naval reactor branch.

The reactor will produce a minimum of 60,000 electric kw with, according to AEC Commissioner Thomas E. Murray, "good possibilities of much higher output." AEC hopes to have the reactor in operation in three to four years.

The reactor may be located at or near one of AEC's gaseous diffusion plants. "If this is done," Murray said, "the unit would supply but a very small fraction of the mammoth power requirements for such a plant. Any higher power costs would have a very small effect on the Commission's overall electrical operating expense."

"The Commission," according to Murray, "will welcome offers from industry to invest risk capital in the building of the steam and turbine portions, as well as in the operation of the entire plant."

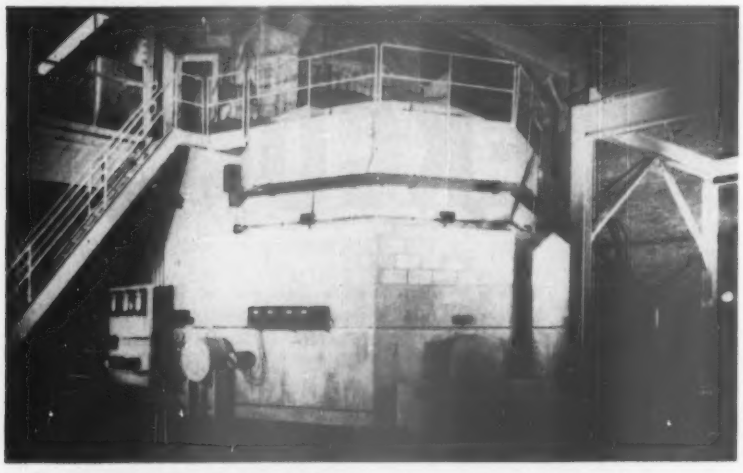
Despite the fact that a Navy man heads the project, AEC has told the Joint Committee on Atomic Energy, "You may rest assured that this reactor will be . . . completely civilian."

In commenting on the AEC action, Chairman Cole of the Joint Congressional Committee on Atomic Energy said, "It is gratifying indeed to see the Atomic Energy Commission moving so swiftly in carrying out the will of Congress in this project. When the Joint Committee on Atomic Energy first saw the President's proposed budget for the coming year, we realized that it made no provision for getting on with development of a full-scale atomic power plant. As a result of our review of this situation . . . there was included, entirely on Congressional initiative, an authorization to permit the start of construction this year of our first atomic power plant."

British to Build Breeder Power Reactor in Scotland

England is searching for a site in Scotland for a large power reactor that will utilize the breeding principle. According to reports received here, the reactor will produce about 50,000 kw of electric power and will take three years to build.

Meanwhile, work is continuing on the natural uranium reactor being built at Calder Hall. Its foundations were laid in June, and the reactor will take two years to complete. It will generate 40,000 kw at a price about twice that of power produced by conventional methods.



EXPERIMENTAL BREEDER REACTOR (EBR) at the National Reactor Testing Center at Arco, Idaho, is shown in this first-released photo. This reactor was the first actually to "breed" at least as much fissionable material as it used. It was also the first reactor whose heat was used to generate electricity

Britain Speeds Work on Industrial Nuclear Power

Britain is establishing a form of government corporation to hasten development of industrial nuclear power, according to reports received here. The move is being made to counteract a coal shortage expected within 15 years. Details will be published next month.

Energy from Hanford Reactor to Heat Buildings

Energy from a reactor now being built at the General Electric-operated Hanford Works in Richland, Wash., by Kaiser Engineers will be used for space heating. While this is the first such useful application of atomic energy in the United States, the British heated buildings with energy from the coolant system of the BEPO reactor in 1952 (NU, Mar. '52, p. 58).

Heat developed in the coolant water of the new Hanford reactor will be transmitted through a secondary water circuit and used to heat the air in several buildings. A steam heating system will automatically take over when the reactor shuts down.

The heat will be equivalent to that needed to heat a thousand homes.

The initial cost of the system will be $614,000—this is $444,000 more than a conventional heating unit. The extra cost will be paid off in 7.5 years by the estimated fuel saving of $59,000 a year. The system will cost $2,200 annually to operate, not counting repairs or upkeep.

Temperatures in the circuit have not been released, but water drawn from the Columbia River at tempera-

tures varying seasonally from 4 to 21° C goes back to the river (after cooling the reactors) at "less than boiling temperature."

Information concerning the date the new reactor will start to operate is not available, but it is known that the $110-million current expansion program will taper off toward the end of next year.

Cole Suggests Industry Build Mobile Reactors

Private industrial development of special-purpose power reactors was suggested in a speech on October 29th by Representative W. Sterling Cole, chairman of the Joint Congressional Committee on Atomic Energy.

Floating units could be used to supply electricity to disaster-struck areas in peacetime and to bombed-out ports and military beachheads during a war. He noted that they would be free from any fuel-supply problem.

He stated, "The urgency of the continental defense problem suggests a market for small packaged power plants to supply electricity to operate remote radar warning stations and interceptor bases."

The Greenland base was mentioned as an example of a location that would be difficult to supply with fuel in the event of a war. Even now, it costs 4 cents per kilowatt-hour (NU, Apr '53, p. 32) to supply Thule Air Base with power. This compares with one-half cent per kilowatt-hour in New York City—"a difference of 800 per cent."

Cole asked, "Is there any reason why a private atomic power industry should not compete to develop and manufacture units for this application just as the electronics industry has developed and sells—at a profit—competitive pieces of electronics gear to provide the warnings themselves?"

Design of Power Reactors Discussed at Argonne

Technical approaches to the problem of economically feasible nuclear power were discussed at a classified Atomic Energy Commission information meeting held in October at Argonne National Laboratory. The effect of these problems on the over-all U. S. reactor development program was also considered.

The meeting was attended by representatives of the national laboratories, educational institutions, and industrial

The Editors Hear . . . .

▶There has been a tightening up on release of information throughout the atomic energy project. Despite the common feeling that this has come on direct order from AEC chairman Strauss, this does not appear to be the case. Rather actions on several specific cases by Strauss and the AEC staff's interpretation of what it believes his philosophy to be have led to the clamping down.

▶Principal action taken by AEC to effect tighter information release policies has been the issuance of a General Manager's memorandum to all AEC Operations Office staffs requiring that the release of all public information of a "nonroutine" nature must be cleared through Washington. Most field information officers are applying the strictest interpretation of what is "nonroutine." Although release of technical information is theoretically not affected by this order, if such information is interpreted to have broad public or industrial interest, it must go through Washington.

▶A key reactor authority thinks it will cost several hundred million dollars, including research and development and pilot plant work, to get to the point where construction could be started on what would be predicted to be an economic power reactor.

▶Recommendations coming out of the tripartite declassification conference at Chalk River last April (NU, May '53, p. 74) were expected to come before the AEC this fall. One point up for consideration is the broadening of access to classified reactor technology by modifying clearance requirements.

▶Although he wants to see increased expenditures on atomic weapons research and feels that peacetime nuclear power should take a back seat to our military program, Chairman W. Sterling Cole of the Joint Committee on Atomic Energy told NUCLEONICS last month that he still plans to introduce in Congress next month the amended Atomic Energy Act that AEC will recommend. After an extended series of hearings, Cole is hopeful that a bill will be reported out of his committee before summer that will provide industry with incentive to work in this field.

▶At the request of the Joint Committee, AEC is preparing a limited report on the "social, political, economic and international effects" of the development of nuclear power, as called for by Section 7b of the Atomic Energy Act.

▶Also at the request of the Joint Committee, a special committee of the American Bar Association completed work last month on a draft of revised atomic energy legislation. On this committee were E. Blythe Stason (U. of Michigan), Gordon Dean, E. J. Putzell (Monsanto), Casper W. Ooms, William T. Gossett (Ford Motor Co.), Robert H. Gerdes (PG & E) and Paul W. McQuillen (Sullivan & Cromwell).

▶The whole reactor safeguard picture has brightened considerably as the result of very important tests conducted in recent months at the National Reactor Testing Station in Idaho. Affected particularly are university and non-AEC groups interested in research reactors.

▶It now appears likely that industrial nuclear power groups will be able to get long-sought-after "type C" patent clauses in their contracts with AEC. This will permit companies to get patent rights to inventions that are useful in the companies' normal line of business.

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organizations interested in the nation's atomic energy program.

Dale Hammond was general chairman. Chairmen at the various sessions were: R. A. Bowman, Bechtel Corp.; R. B. Briggs, Oak Ridge National Laboratory; T. B. Drew, Columbia University; S. Lawroski, ANL; C. R. McCullough, Monsanto Chemical Co.; Marvin Mann, duPont Co.; W. T. Moore, Babcock and Wilcox Co.; R. P. Peterson, AEC-Washington; H. W. Russell, Battelle Memorial Institute; T. M. Snyder, Knolls Atomic Power Laboratory; D. E. Thomas, Westinghouse Atomic Power Division; L. A. Turner, ANL; Clarke Williams, Brookhaven; and W. H. Zinn, ANL.

Zuckert Favors Loose Law to Aid Industrial Power

Legislative action by Congress is necessary to encourage investment of private capital in nuclear power development, according to AEC Commissioner Eugene M. Zuckert.

In a speech before the National Industrial Conference Board in New York, he said, "Any legislation will have to give the Commission considerable discretion in order that we may be able to move dynamically in response to developments within the industry.

"This does not mean that the Commission will be able to act arbitrarily . . . its program would have to have approval from both the executive and legislative branches of government before . . . any large-scale commitment of government funds."

AEC Approves Study of Ship Propulsion Power

A proposal by the Newport News Shipbuilding and Dry Dock Company for a special company-financed study of the application of nuclear power to the propulsion of ships has been approved by the Atomic Energy Commission.

The company obtained experience in the nuclear field as a subcontractor on the now terminated project for an aircraft carrier reactor. Six of its engineers recently completed studies at the Oak Ridge School of Reactor Technology.

Admiral Carney Urges Nuclear-Powered Fleet

Pointing out the advantages to be derived from the use of nuclear fuel in naval vessels, Admiral Robert B. Carney, Chief of Naval Operations, in a talk in Pittsburgh last month said, "It would be folly for this country to wait until it is driven to the development of nuclear fuels."

Referring to the submarine reactor prototype, Carney stated, "The new submarine engine has been tested over an extended period and . . . it is better than our expectations. Anybody knows that if you can power a submarine with atoms, you can power any kind of a ship, including the aircraft carrier and the guided missile ship."

RAW MATERIALS

• **Wyoming.** An important new discovery of uranium ore has been made 50 miles east of Lander, Wyoming. The ore is carnotite—uranium oxide with varying amounts of vanadium oxide. The find is described as being of commercial grade, and there are surface indications that the ore extends 17 miles. The lands are all in the public domain. Legislation is pending in Congress to clarify the status of oil and gas leases held on parts of the area.

• **Peru.** Legislation is pending to permit private exploitation of uranium ores. A bill before the Peruvian Congress authorizes formation of a committee to draw up regulations and to fix prices for ore, all of which will be bought by the Peruvian government. The arrangement would be similar to those existing in the United States and Canada.

• **Australia.** Many new discoveries have been made and are being carefully examined. The government is intensifying efforts to stimulate private prospecting. Although all mined ore must be sold to the government, prospecting and mining of uranium is no more regulated than for any other material. A definite policy on prospecting and exploitation of uranium is expected to be formulated before the end of the year.

Three new deposits have been discovered in the Crocker's Well area of South Australia. Surface indications in two of them are exceptionally good. Diamond drilling is expected soon. The State-owned Port Pirie treatment works are expected to begin producing high-grade uranium salt around June of next year. A $250,000 pipeline will bring water from the Murray River.

Two major discoveries plus several promising reports based on an aerial survey are being investigated in the

Northern Territory. Based on surface drilling, indications are good at the Coronation Hill deposit (about 50 miles from Pine Creek). The other promising field is located about 11 miles from Katherine. It is known as the ABC field.

The Rum Jungle field is presently limited to 168 square miles. Ore is being produced from a 30-ft-deep open cut. A shaft has been sunk to 490 ft. The treatment plant should begin operating during the latter half of 1954.

There are also promising developments in the Mount Fitch area.

IN BRIEF

• **Reactor for India.** The first reactor in India will probably be in operation within two or three years. Although the reactor is being built for "peaceful purposes," NUCLEONICS was informed that no design details can be made available to the press or for export. The Indian AEC is building an impressive home at Colaba.

• **Ceramics technology.** The uses of ceramics in reactors was discussed at an information meeting held at Oak Ridge National Laboratory in October.

• **ORINS sponsors.** Southern Methodist University and Tuskegee Institute have been elected sponsoring universities of the Oak Ridge Institute of Nuclear Studies.

• **Westinghouse expansion.** An equipment development section has been set up within Westinghouse's atomic equipment department. It will develop and test improved plant components and equipment for nuclear power plants.

• **German center.** Production of nuclear power and applied research directed towards other peaceful uses of nuclear energy will be the objectives of a new facility to be built by the West German government as soon as the Bonn and Paris agreements have been negotiated.

• **Power study.** The Atomic Energy Commission has approved the request of the Foster Wheeler-Pioneer Service power study team to add the Diamond Alkali Company of Cleveland, Ohio, as an associate in its study.

• **Counter symposium.** Arrangements have been completed to hold the second Scintillation Counter Symposium (NU, Oct. '53, p. 72) at the Shoreham Hotel in Washington on January 26 and 27, 1954.

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MODEL	RADIATION SPECTRUM (Kev. effective)	SENSITIVITY RANGES	TOTAL DOSE (roentgens)	USE
601	30 to 400	10-30-100 r/min.	1 to 999	X-ray therapy
602	30 to 400	100-300-1000 r/min.	10-9990	X-ray therapy
603	400 to 2000	5000-15000-50000 r/min.	500-499, 500	On telecurie Gamma sources
604	20 to 50	100-300-1000 r/min.	10-9990	Low energy therapy
605	400 to 2000	1-3-10 r/min.	0.1-99.9	Gamma ray sources
606	400 to 2000	10-30-100 r/min.	1-999	Gamma ray sources
607	400 to 2000	100-300-1000 r/min.	10-9990	Gamma ray sources
608	30 to 400	10-30-100 r/hr.	1-999	Survey in vicinity of X-ray machines
609	Not Applicable	10-30-100 r/min.	10-9990	Beta-Gamma skin dose
610	I^{131} and AU^{198}	1-3-10 mc. I^{131}	Not Applicable	Isotope assay
611	400-2000	0.5-1.5-5 r/min.	0.05-49.95	Gamma ray sources

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Victoreen Instrument Co., 5806 Hough Ave., Cleveland 3, Ohio. The model 575 integrating ratemeter uses thimble ionization chambers for measurement in roentgens of radiation rate and total dose. Standard probe covers 30–400 kev, 1–999 roentgens total dose in 1-r steps, and intensities of 1–100 r/min in ranges of 0–10, 0–30, and 0–100. Interchangeable probes are available for measuring total dose and intensities a thousand times higher and lower than the standard probe. Radiation energies from 30 kev to 2 Mev are covered with chambers calibrated in roentgens. A cable up to 200 ft long connects the control unit to the probes. (P-1)

Coincidence Scaler

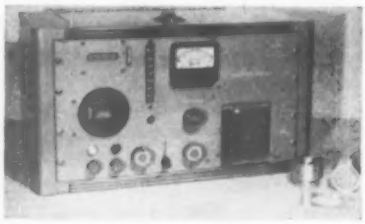
Radiation Instrument Development Laboratory, 2337 W. 67th St., Chicago 36, Ill. All four channels of the model 400 coincidence-anticoincidence scaler may be used for coincidence counting with the fourth channel also designed specifically for anticoincidence counting. Input sensitivity is 1 volt, negative. Channel deadtime is < 10 μsec. Scale-of-64 provides scale selection of 4, 8, 16, 32, or 64. Counter voltage is continuously variable from 500 to 2,500 volts with electronic regulation of 0.01% per 1% change in line voltage. (P-2)

X-Ray Film

E. I. du Pont de Nemours & Co., Wilmington, Del. The type 510 X-ray film can be used at 10–20 kv-peak to examine low-opacity materials, e.g., aluminum and magnesium, or, with million-volt X-ray or betatron equipment, steel up to 3 in. Since the film is made to indicate detail, it is one-third as fast as type 506 industrial X-ray film. Type 510 is designed for use without calcium-tungstate intensifying screens. It is available in all standard sizes and is packaged as non-interleaved film. (P-3)

Linear-Amplifier Unit

Detectolab, Inc., 6544 Sheridan Rd., Chicago 26, Ill. This unit includes the models DZ16 pulse generator, DZ15 single-channel analyzer, and DR8 linear amplifier. The pulse generator, similar to ORNL model Q-1066, provides pulse heights variable over five ranges, 1, 3, 10, 30, and 100 mv, at a frequency of 3,600 cpm; output is positive or negative with 10^{-8}-sec rise time and 350-μsec decay time. The DZ15 differential pulse-height discriminator is a modification of ORNL model Q-1192-5, using type 404A pentodes. The linear amplifier, for general laboratory work, is identical with the ORNL Q-541 A1 circuit. (P-4)



Alpha Scintillation Scaler

Reed-Curtis Scientific Instrument Co., Inc., 307 Culver Blvd., Playa del Rey, Calif. This scaler, incorporating a built-in light-tight chamber with an RCA 5819 photomultiplier for scintillation counting, can be used for α, β, and γ scintillation counting through the use of changeable phosphors. External connectors are provided for accessory counters. Instrument has binary scales up to 256; mechanical register indicates up to 10,000. Count is presetable from 40 to 256,000. High-voltage supply is 750–1,500 volts, d-c. Alpha phosphor and sample included; β, γ, and neutron phosphors are available. (P-5)

Predetermining Counter

Computer Research Corp., 3348 W. El Segundo Blvd., Hawthorne, Calif. The electronic predetermining counter is capable of counting up to 1,800,000 cycles per minute without the use of vacuum tubes. The ferro-resonant circuit is insensitive to heat, shock, and vibration. The unit can start or stop counting on any count, control operations by the use of frequency division, or emit an output pulse at any predetermined count. (P-6)

Counting-Rate Meter

Measurement Engineering Ltd., Arnprior, Ontario, Canada. The AEP 1902A counting-rate meter has eight ranges from 0–100 to 0–25,000 cpm

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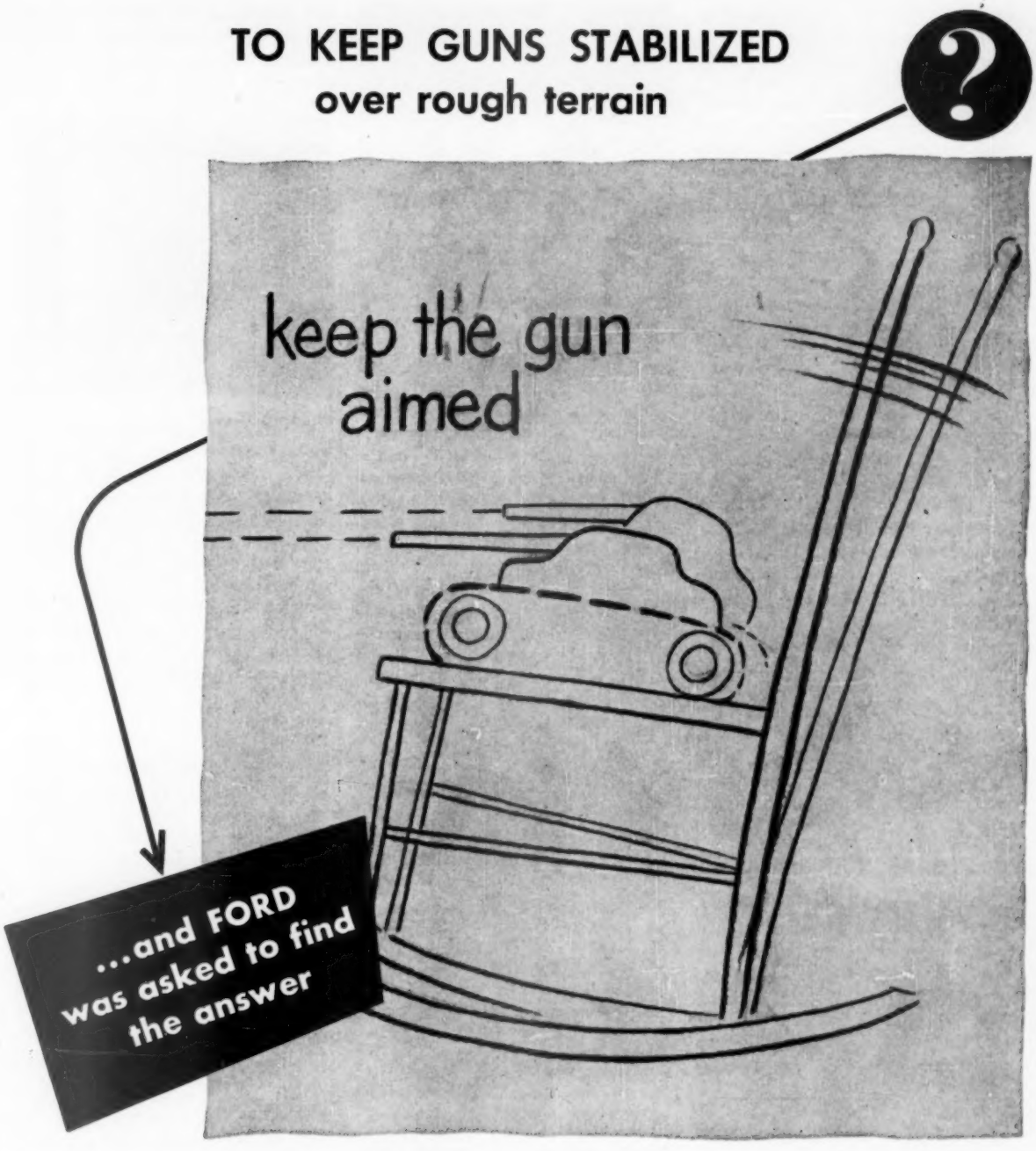

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with an accuracy of 1%; corresponding resolving times are 8,000 to 32 μsec. It is designed for negative input pulses from 50 mv to 100 volts; modification allows use of positive input signals. Counting losses are 1⅓% at full scale on all ranges for random pulses. Integrating time constants are 3.5, 14, and 56 sec. (P-7)

Electronic Null Detector

Deltron, Inc., Box 192, Glenside, Pa. The model 200A null detector is a quasilogarithmic voltmeter, used as a balance indicator for a-c measuring bridges and as a signal tracing voltmeter. On-scale range is 120 db; overall gain of >60 db results in 1% meter deflection for input of <50 mv. Full-scale sensitivity is variable from 5 to 100 volts. Useful frequency range is 10 cycles to 5 Mc. The phone terminals provide an increase in sensitivity of 20 db. (P-8)

Pulse Generator

Technitrol Engineering Co., Philadelphia 33, Pa. The Variable Pulser provides pulse repetition rates from 20 cps to over 2.0 megacycles. It is designed to convert the output of any standard oscillator, with 3 volts rms or greater, into a series of pulses, one for each oscillator cycle. Rise and fall times are 0.05 μsec; pulse width is variable from 0.2 to 5.0 μsec and amplitude from zero to over 40 volts. A trigger pulse precedes the output pulse in time. (P-9)

Ultracentrifuge Cell

Specialized Instruments Corp., 668 O'Neill Ave., Belmont, Calif. This synthetic-boundary ultracentrifuge cell is claimed to extend the range of ultracentrifugal analysis downward in the macromolecular region from molecular weights of about 10,000 to about 500. Operation depends on layering of supernatant over mixture under study, thus producing a boundary away from the meniscus. Measurements of the movement of this boundary are made by conventional optical methods. The technique is said to permit the formation of sharp boundaries in the presence of appreciable diffusion. (P-10)

Scintillation-Well Counter

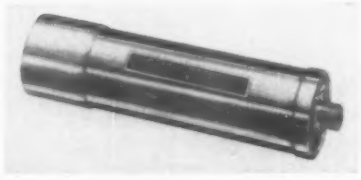
Nuclear Instrument & Chemical Corp., 229 W. Erie St., Chicago 10, Ill. The model DS-3 scintillation-well counter is said to allow measurement of activities down to 0.00001 μc. For sample volumes <2 cm³, the instrument is insensitive to sample volume. Gamma-emitting samples are prepared in standard test tubes or centrifuge tubes and inserted directly into the crystal well. Over-all efficiencies of 43% and 51% can be obtained for Co^{60} and I^{131} gammas. Detector uses NaI(Tl) crystal and has plateau length of at least 200 volts. DuMont 6292 phototube and built-in preamplifier provide output pulse in excess of ¼ volt. (P-11)

Nuclear Timer

Liebel-Flarsheim Co., Cincinnati 15, Ohio. The model 2D nuclear timer integrates total time from 1 sec to 60 min. Regardless of starts and stops, accuracy is $\frac{1}{10}$ sec. Normally open and normally closed operation are provided for. Four motors available are 115 volt, 50 or 60 cycle, and 230 volt, 50 or 60 cycle. Dual dial markings permit direct reading of preset and elapsed time. (P-12)

Hydraulic Servo Valve

Sanders Assoc., Inc., Nashua, N. H. This two-stage, four-way hydraulic servo valve has internal mechanical feedback for transformation of low-level electrical information into controlled hydraulic energy. A clearing force of up to 500 lb in the first stage removes particles tending to jam the valve. Frequency response is flat from 0 to 150 cps. Output is linear up to 14 hp, with no external leakage and zero signal leakage of 60 cm³/min. Power amplification is 5,000 with pressures up to 3,000 psi. Valve has flow of up to 12 gal/min. (P-13)



Scintillation Counter

Nuclear Research and Development, Inc., 6425 Ezel Ave., St. Louis 14, Mo. The SC-33 scintillation counter, 2-in. diameter × 6½ in., is light weight for

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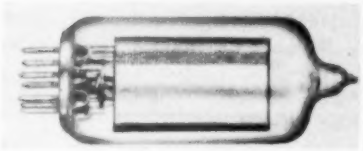
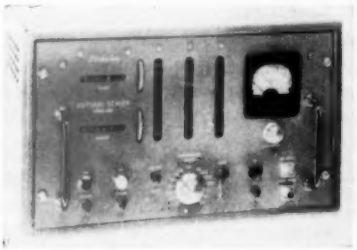
portable equipment. Threaded end permits attachment of accessories. The phosphors, maximum diameter 1½ in., are used with an RCA 6199 photomultiplier, which is pressed against the Plexiglas crystal mounting with a small amount of DC-200 silicone inserted between. Alpha, beta, and gamma phosphors are obtainable as attachments. (P-14)



Miniature Hydrogen Thyratron

Chatham Electronics Corp., 630 Mt. Pleasant Ave., Livingston, N. J. The type VC-1258 hydrogen thyratron, for pulse-generating applications, handles peak power up to 10 kw. Rating is 1,000 peak anode volts, 20-ampere peak anode current, and 40-ma average anode current. Repetition rates in excess of 10,000 pps are possible at reduced ratings. Tube fits standard ceramic miniature socket. (P-15)



Decimal Scaler

Beckman Instruments, Inc., Berkeley Scientific Div., 2200 Wright Ave., Richmond, Calif. The model 2001 decimal scaler, using a scale of 1,000, is a modification of the model 2000. Preset counts and scaling factors provide for operating external registers or other devices. A drum-type time clock is located beneath the mechanical register. High-voltage supply regulation is said to be suitable for scintillation counters as well as G-M tubes. (P-16)

INDUSTRY NOTES

▶**Industrial Hygiene Associates,** 123 Wiswall Rd., Newton Centre 59, Mass., has been organized as a consulting service by Melvin W. First, Sc. D., consulting and research engineer formerly of the Harvard School of Public

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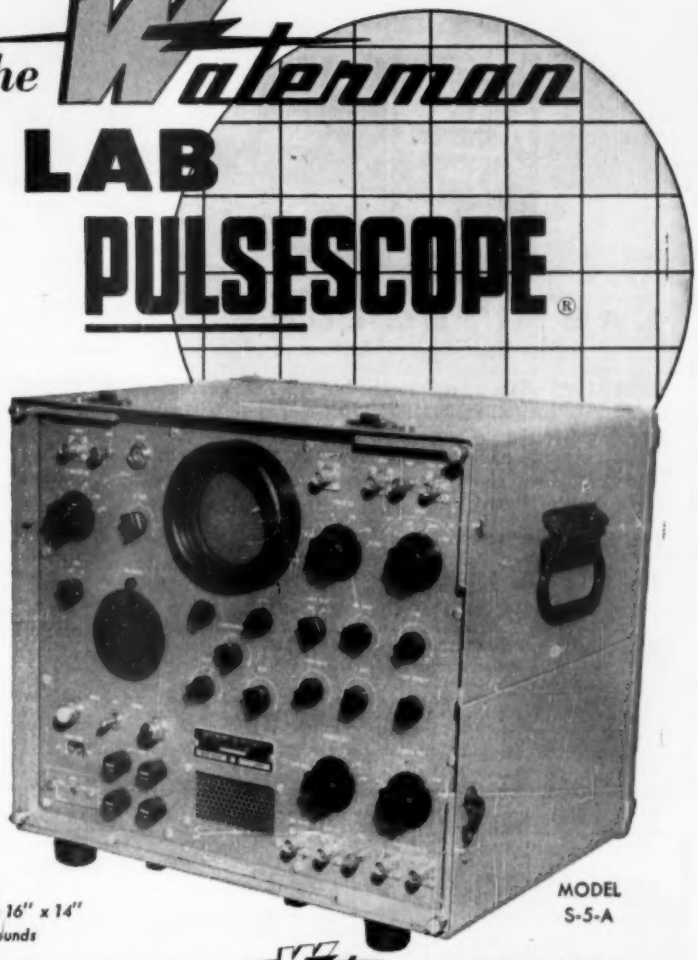

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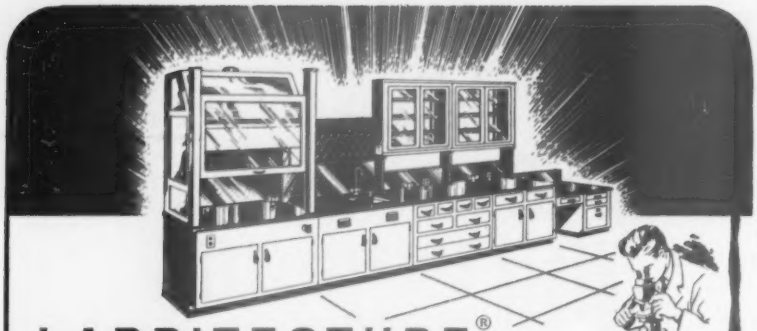

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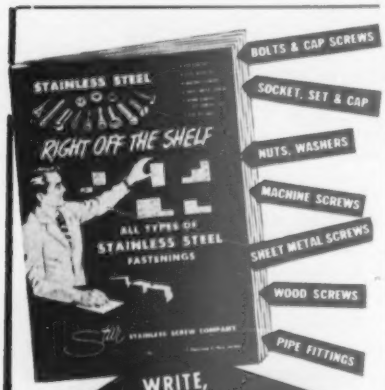

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Health, Samuel Levin, health physicist, and Fred J. Viles, Jr., industrial hygiene engineer, both of the Occupational Medical Service, M. I. T., and Albert O. Seeler, M. D., industrial hygiene physician on the staff of the Harvard Medical School. Activities include plant industrial hygiene appraisals, radiation surveys and shielding design, air-pollution studies, and design of engineering controls.

▶**Beckman Instruments, Inc.,** South Pasadena, Calif., has delivered the first of 100 mass spectrometers on order to Carbide and Carbon Chemical Co., AEC operating contractor of Oak Ridge, Tenn.

▶**Servomechanisms, Inc.,** Post and Stewart Aves., Westbury, N. Y., has formed a Components Division, at 625 Main St., Westbury. Products of the new division include miniature servo and instrument motors and mechanical development apparatus.

LITERATURE AVAILABLE

Dry-type transformers. Catalog 353 describes line of transformers that are not oil-filled. *Hindle Transformer Co., Inc., Woods Church Rd., Flemington, N. J.* (L-1)

Mass spectrometer analytical service. Bulletin gives sample requirements and typical analyses. *Consolidated Engineering Corp., 300 N. Sierra Madre Villa, Pasadena 8, Calif.* (L-2)

Recording potentiometer. Booklet describes potentiometer that permits chart speed changes "on the line" by screwdriver adjustment. *Weston Electrical Instrument Corp., 614 Frelinghuysen Ave., Newark 5, N. J.* (L-3)

Mass spectrometer analysis. Booklet GEC-587A explains use of mass spectrometer or chemical analysis, together with installation and maintenance information. *General Electric Co., Schenectady 5, N. Y.* (L-4)

Large-screen oscilloscope. Brochure gives specifications on model 21A 21-in., rectangular cathode-ray oscilloscope. *Technomatic Instrument Co., 2316 Pico Blvd., Santa Monica, Calif.* (L-5)

Viscosity information. "Article Reprint Request Sheet" lists reprints available on viscosity and related subjects. *Brookfield Engineering Laboratories, Inc., Technical Service Dept., Stoughton, Mass.* (L-6)

Liquid-level gages. Bulletin gives

specifications for transparent gages. *Jerguson Gage & Valve Co., 80 Fellsway, Somerville 45, Mass.* (L-7)

High-vacuum applications. Bulletin 10F discusses design of high-vacuum systems and selection of components. *Central Scientific Co., 1700 Irving Park Rd., Chicago 13, Ill.* (L-8)

Gas analysis unit. Bulletin GMH-853 describes relative thermal conductivity unit for gas studies. *Gow-Mac Instrument Co., 100 Kings Rd., Madison, N. J.* (L-9)

Cathode-ray oscillograph. Bulletin furnishes specifications and 3-dimensional mock-up of type 301-A oscillograph. *Allen B. Du Mont Laboratories, Inc., Technical Sales Dept., 760 Bloomfield Ave., Clifton, N. J.* (L-10)

Water sampling. Leaflet 28X7969 discusses factors involved in obtaining samples for control of water conditions in a power house. *Allis-Chalmers Mfg. Co., 1316 S. 70th St., Milwaukee, Wis.* (L-11)

Steam generators. Bulletin G.B.-153 describes generators, heat-recovery units, and process equipment. *Union Iron Works, Erie, Pa.* (L-12)

Single-seated valves. Catalog 1500B describes automatically controlled, solenoid-operated, manually operated valves. *Annin Co., 3500 Union Pacific Ave., Los Angeles 23, Calif.* (L-13)

Electronic analog computing devices. Catalog covers latest developments, new components, and prices. *George A. Philbrick Researches, Inc., 230 Congress St., Boston 10, Mass.* (L-14)

Nondestructive testing equipment. Bulletin 50-110 describes equipment for ultrasonic testing, including contact and immersed techniques. *Sperry Products, Inc., Danbury, Conn.* (L-15)

Electron microscope. Pamphlet 2J6851RE describes the type EMT table model. *RCA Victor Div., Eng. Products Dept., Camden 2, N. J.* (L-16)

Electrical measuring instruments. Catalog E-16 gives data on resistance standards and resistance-measuring apparatus. *Gray Instrument Co., 64 W. Johnson St., Philadelphia, Pa.* (L-17)

Grating spectrographs. Catalog G2-53 gives specifications on adjustable and fixed-position spectrographs and accessories and suggests laboratory layouts. *Jarrell-Ash Co., 26 Farwell St., Newtonville, Mass.* (L-18)

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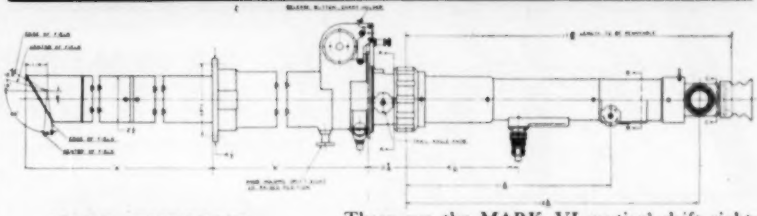

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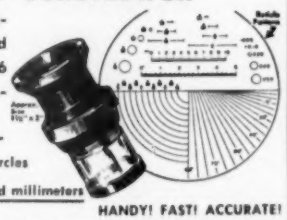

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INDEX TO ADVERTISERS

December, 1953

Academic Press Inc., Publishers 54
Atomic Instrument Company ..... Third Cover
Automatic Switch Co. 66
Berkeley Div., Beckman Instruments, Inc. 57
Bersworth Chemical Co. 88
Burndept, Ltd. 87
Carboloy Dept. of General Electric Co. 68
Century Geophysical Corp. 61
Chicago Standard Transformer Corp. 62
Consolidated Vacuum Corporation ..... Second Cover
Edmund Scientific Corp. 79
Ekco Electronics, Ltd. 69
Fairbanks, Morse & Co. 5
Ford Instrument Company. 75 80
General Electric Company 6
Jarrell-Ash Company 64
Keleket Instrument Div. 54
Kewaunee Mfg. Co. 67
Kollmorgen Optical Corporation 72
Metalab Equipment Corp. 78
Michigan Chemical Corporation 80
Minneapolis-Honeywell Regulator Co., Industrial Div. 4
National Radiac 78
Nuclear Instrument and Chemical Corporation ..... Fourth Cover
Penberthy Instrument Co. . 79
Philips' Gloeilampenfabrieken, N.V. 55
Radioactive Products, Inc. 65
Rockbar Corporation 64
Sanborn Company 2
Searchlight Section 79
Star Stainless Screw Co. . . 78
Technical Associates 63
Technical Service Corp. 88
Titeflex Inc. 3
Victoreen Instrument Co. . . 73
Waterman Products Co., Inc. 77
Where To Buy 79

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SEARCHLIGHT SECTION
(Classified Advertising)
H. E. Hilty, Mgr.

EMPLOYMENT 87
EQUIPMENT (Used or Surplus New) 87

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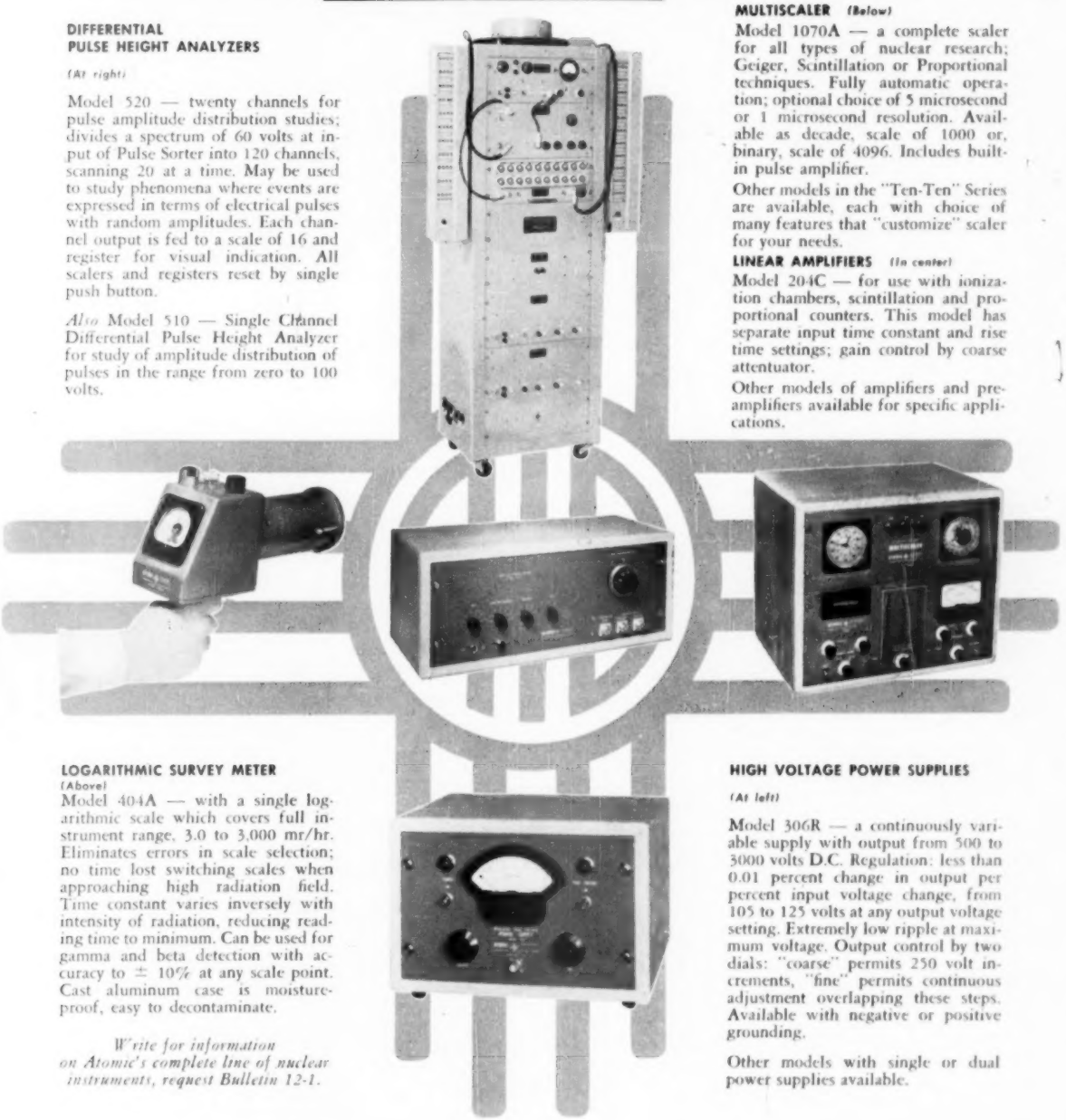

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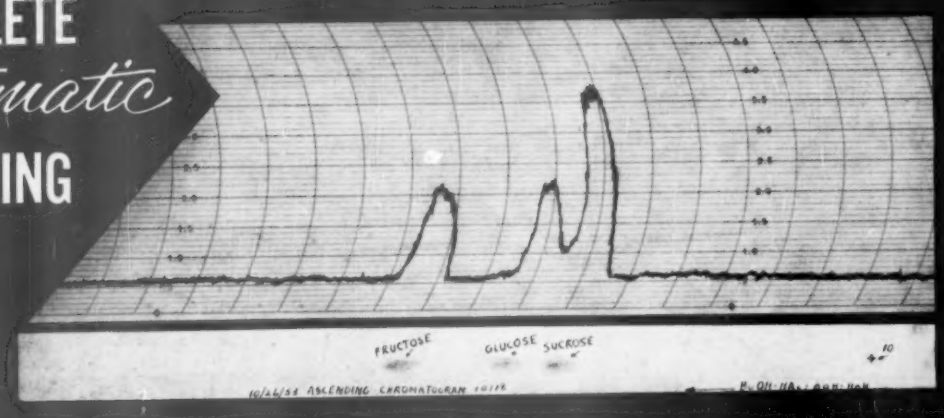

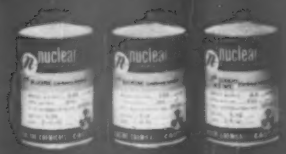

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